THE PLANT WORLD

Plant Life of Our Earth

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DIRECTOR OF BROOKLYN BOTANIC GARDEN

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To
My Daughter
Ruth Prudence Gager

LAMARCK

The science which has for its object a knowledge of plants is, I do not hesitate to say, of all the subdivisions of natural history, that which presents at the same time the most numerous objects of utility and the most varied charms. The wholesome foods of every kind which plants offer to man for his most essential needs, the innumerable resources that they furnish to medicine in the treatment of diseases, the multifarious tributes with which they enrich nearly every art, and finally the charms which they possess, all in a word, concur to assure a marked pre-eminence to the study of that extensive branch of human knowledge and to make one realize its inexhaustible attractions.—*Jean Baptiste Lamarck* (1744-1829).

CHAPTER I

THE BEAUTY AND IMPORTANCE OF PLANTS

It is the *beauty* of the plant world that chiefly impresses most people. Perhaps it is not too much to say that the average man (if such a one exists) is impressed only by its beauty. The charm of landscape is due in large measure to vegetation, and one who has experienced the glories of autumn scenery, in our New England states and elsewhere, realizes what wonderful effects are possible when Nature paints with autumn foliage.

But not only in the country do we cherish the beauty of vegetation. How unlovely and forbidding a city would be without its parks and gardens with their trees, shrubs, and lawns, and without trees on any of its streets. "If you get simple beauty and naught else," said Browning, "you get about the best thing God invents."

Importance of Plants in Our Daily Lives

But plants affect our daily lives in many ways besides by their beauty. For example, someone has said that, in a very real sense, civilization is founded upon wood. We live in wooden houses (most of us in America), sit in wooden chairs, eat from wooden tables. If we take a railroad journey, we buy a ticket made of wood pulp, pay for it by "paper" money made of linen fiber, and ride in cars that run on rails supported by wooden ties; and the telegraphic message that insures the safe running of our train is carried by wires supported by wooden telegraph poles. Each morning we read the news of the past twenty-four hours printed on wood pulp bleached white and pressed thin, for that is what newsprint paper is.

For all of our food we are dependent either directly or indirectly upon plants, since the meat that we eat is derived from plant-eating and not from carnivorous animals. All drinks (except water)—coffee, tea, cocoa, chocolate, every alcoholic

beverage, lemonade, and others—are derived from plants. In some countries uncivilized aborigines are dependent on plants for even the water they drink (*see* page 56). Flavoring extracts and perfumes (except as we have substitutes from coal-tar derivatives) and many medicines are made from plants.

We must avoid some plants as poisons, and seek medical aid to protect us against microscopic plants which cause disease and death. Certain microscopic plants (some of the fungi) live normally in the human ear; some in the stomach, causing food to ferment instead of to digest; some in the human skin, causing such diseases as ringworm (due to a fungus in the skin).

For the ripening and flavoring of cheese, the retting of flax and the raising of bread, we are indebted to low forms of plant life. When we try to cultivate plants as crops, or raise flowers in our gardens we must constantly fight other plants that live as parasites on the plants we try to grow—"rust" on cereals and carnations, "smut" on corn, "blight" on pears, "scab" on apples. The prices we pay depend, in part, on the ravages of plant diseases. Statistics of the United States Department of Agriculture indicate (in the words of Professor Whetzel) "that approximately one bean in every dozen, one apple in every seven, one peach in every eight, one bushel of Irish potatoes in every twelve, and one bushel of wheat in every ten, are destroyed annually by diseases of these crops."

CHAPTER II

WHAT IS A PLANT?

WE SAID that the "average" man is most impressed with the beauty of plants, but the botanist, while appreciating this beauty, is most concerned with plants as living things. For plants are very much alive. What does it mean to be alive? Chiefly this: a living thing (plant or animal) has the ability to take in material from outside and *transform it into substance like itself,* so that it is nourished and kept alive, grows from within, and reproduces its kind. A non-living thing, such as a stone, cannot do any of these things. If it "grows" at all, it merely enlarges by the accretion of material on *the outside.* Such material is not transformed into substance like itself, and the stone cannot reproduce other stones.

Plants Versus Animals

Plants and animals are alike in that they both are born, feed, grow, breathe, reproduce, and move (both motion and locomotion). Contrary to a common misconception, most plants are capable of motion and some of locomotion by their own efforts, while some animals (*e.g.,* sponges and oysters) are capable of locomotion only when very young, and are as fixed as trees when mature.

But the fundamental difference between plants and animals is that plants can make living matter from non-living matter, while animals cannot. Plants do this by means of their green substance, which occurs chiefly in leaves and which is therefore called "leaf green" or *chlorophyll.* No animals possess chlorophyll.

Cells and Protoplasm

Plants and animals are alike also in that they are both composed of *cells.* This fact was discovered by the English bot-

anist, Robert Hooke, about 1665. The cell-theory was elaborated for plants by the German botanist, Matthias Jakob Schleiden, in 1838. Theodor Schwann, also of Germany, performed a similar service for zoology in 1839. A plant cell, as now defined, is a unit of living matter, called *protoplasm,* usually enclosed by a wall of *cellulose.* The walls of animal cells are never of cellulose.

Fig. 1—MATTHIAS JAKOB SCHLEIDEN

Co-founder with the zoologist Schwann of the cell-theory. He gave a great impulse to botanical research

Protoplasm is the most wonderful substance in the world. It was not discovered until about 1835, and after having had several names was called protoplasm by the German botanist, Hugo von Mohl, in 1846. It is not a chemical compound, but a mixture of extremely minute *solid* particles of various kinds, held in suspension (not solution) in a *liquid,* which also holds substances in solution and is permeated by various *gases,* such as oxygen and carbon dioxide. The chemist says the matter is in three "phases," and calls the mixture a "colloidal" system because it is similar in structure to glue, a well-known colloid.* In a colloidal system the substance whose particles are in suspension is itself not soluble in the liquid. Silver, not soluble in water, may exist in the colloidal state in water. The particles are not quite as small as molecules of silver. They are about the size of the wave length of light, and will never settle to the bottom of the dish containing the mixture. On account of the very small size of the particles, an enormous amount of surface is exposed. The colloidal particles each bear a charge of electricity, and adhere in groups and chains. The liquid part of protoplasm also contains countless bodies called *ions,* smaller than the colloidal particles just mentioned and each bearing a unit charge of electricity. Ions result from the dissociation of molecules of soluble substances into their component atoms,

* From the Greek, *kolle*—glue.

each of which bears a definite charge of either positive or negative electricity. An atom with its associated electric charge is an ion. Thus, a molecule of common salt ($NaCl$) is dissociated into a positively charged ion of sodium (Na^+) and a negatively charged ion of chlorine (Cl^-).

Life an Electrical Phenomenon

It is thus seen that protoplasm is a wonderfully delicate and complicated *mechanism,* full of electricity, so to speak, fairly constant for a given kind of plant, but chemically very unstable, being built up and broken down again constantly, without ceasing so long as it remains "alive." Chemically quiescent protoplasm means death. Of and by such a marvelous substance all plants are formed. Life is thus, physiologically speaking, an electrical phenomenon, or rather, a vast series of electrical phenomena. Among the substances contained in the cell are carbohydrates, proteins, fats, and enzymes (to be mentioned later).

The protoplasm of every "kind" (species) of plant or animal differs from that of every other kind, and the *history* of any given kind of protoplasm is of the highest importance, for its history, including its origin and the conditions to which it has been subjected in successive generations, has a great deal to do with its present characteristics. It thus differs from a non-living mechanism like a watch which, though complicated and delicate, is not related in any way to any watches which have existed before it.

The Plant Cell

Summarizing, we may picture a plant cell as a tiny bit of protoplasm (sometimes called the *protoplast*) surrounded by a wall of cellulose. The surfaces of the protoplasm act like a very delicate membrane. A liquid part of the protoplasm (*cell-sap*) occurs in large and small droplets. The spaces filled by these are *vacuoles.* Every cell has a specially differentiated organ called the *nucleus*, which appears more dense than the rest of the protoplasm (the *cytoplasm*) when viewed with a compound microscope. The nucleus is surrounded by the *nuclear membrane*, and is composed of nuclear sap and a substance which

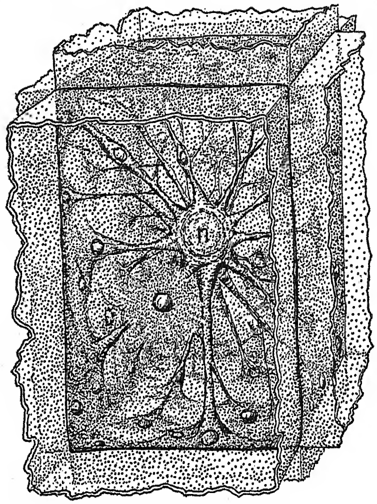


Fig. 2—PLANT CELL SHOWN IN PERSPECTIVE

The protoplasm lines the inner walls, surrounds the nucleus (*n*), and extends in strands from the nucleus to the lining layer

easily stains and is therefore called *chromatin.* At certain times the chromatin divides into little "chromatin bodies" (*chromosomes*). Each of these differs from all the others in its composition.

And, finally, we must visualize the protoplasm of a cell as in constant motion, flowing along the surface of the cell-wall and across the cell in ever-changing strands from wall to wall, from wall to nucleus, the latter also constantly changing its position in the cell. With this thought in mind, how differently one will regard a flower in a vase, a large tree in a field, a meadow, or a lawn.

CHAPTER III

WHAT IS LIFE?

"BUT," you may ask, "where is the *life* of the cell, and *what* is life?" No one can answer those questions. Possibly life, physiologically speaking, may be the sum total of all the activities of the cell. It has recently been suggested that it may be an intra-atomic thing, that is, resulting from the interaction of *electrons* (component parts of atoms), rather than from the interaction of atoms. About all we can say is that we often (though not always) know when life is present, but we know practically nothing as to what life really is. We know that a cell is complicated beyond our ability to comprehend. Hofmeister estimated that a cell of liver contains more than 200,000 billion molecules. Each of these contains many atoms, each atom several electrons. We are staggered by such numbers. We rise in the scale, in succession, from electrons to atoms, ions, molecules, molecular aggregates, non-nuclear unicellular organisms, nuclear unicellular organisms, multicellular organisms. We have plenty of names, but a paucity of understanding!

THE ORIGIN OF PLANTS: ORIGIN OF LIFE

One cannot study the plant world very thoroughly without becoming curious as to the origin of plants, and this, of course, brings one face to face with the question of the origin of life. Those who have carefully studied this question agree that matter in the non-living state must have existed first, then the colloidal state was realized, and finally some particular colloid or colloidal mixture having the properties of protoplasm. Quite probably these primitive units of protoplasm were too small to be seen with the naked eye (although, of course, there were then no animals having eyes to see). They were the first plants, having no green coloring matter, and deriving their necessary energy

by oxidizing iron, sulphur, or some other substance, just as certain bacterial plants do now. Some of these primitive, possibly ultra-microscopic, organisms took in "food," grew, and divided, thus propagating their kind. In time, some of them, after *cell-division,* did not separate into two new organisms, but the two new *daughter-cells* remained attached. In the course of untold ages, we came to have green organisms composed of millions of cells, organized into *tissues* and *organs* (roots, stems, leaves, etc.), until finally the present plant world was realized in all its marvelous beauty and diversity.

Did Plants or Animals Exist First?

The question is sometimes asked as to whether plants or animals existed first. Since all animals, so far as we know, are dependent upon plants for their food, either eating plants directly or feeding on other animals whose food is plants, we must conclude that such animals as we now know could not have existed before there were plants. All we can say is, that if there were ever any animals before there were plants, they must have been different in their food habits and in other ways from animals living today.

CHAPTER IV

A CENSUS OF THE PLANT WORLD

IT HAS been estimated that there are not less than 233,000 different kinds of plants in the world, of which over one half (132,000) are *Flowering Plants* and 3800 are *Ferns*. If we included all the different kinds of plants which lived in previous geological ages, but which are now extinct and known to us only by their "dug up" (*i.e.,* fossil) remains, we would no doubt be truly surprised at the great amount of diversity.

CLASSIFICATION

In fact, the number of kinds is so great as to make it very difficult for us to form an intelligent mental picture of the plant world. The only way we can do this is to carefully *compare* the plants we observe, note their fundamental, as distinguished from their superficial, differences, and then *classify* them into groups, placing those that are fundamentally alike in the same group. Larger groups may be subdivided again and again, by narrowing down the number of points of similarity. For example, all plants either are trees or are not trees. All trees either have cones or they do not have cones. Those that do not have cones either bear acorns or they do not bear acorns. Those that do not bear acorns either bear chestnuts or they do not bear chestnuts. Those that bear acorns we call *Oaks*. So the process proceeds.

Observe, compare, classify, generalize—thus we try to simplify the problem so that we can approach to an intelligent understanding of the enormously complex world of plants.

NAMING PLANTS

We read in Genesis that, after the Lord had "formed every beast of the field" He "brought them unto Adam to see what

he would call them: and whatsoever Adam called every living creature, that was the name thereof. And Adam gave names . . . to every beast of the field." Even now, almost invariably the first question one asks about a plant is its name. This is interesting, for it implies that we naturally "take it for granted" that every plant has a name. Such is the case. That is, every *known* plant has a name, and this means that for thousands of years men have been carefully studying, naming, and classifying plants. When new kinds of plants are discovered, they are first described and classified, and then named.

The naming of plants is second only in importance to studying and understanding them, for unless they are named we cannot conveniently talk about them or refer to them in our writings. From the time of Aristotle, who wrote several books about plants, the question of correctly naming them has been recognized as important as well as difficult, and a system of governing principles has gradually developed constituting an important subdivision of botany known as *nomenclature*. The Fifth International Botanical Congress held in Cambridge, England, in 1930, and attended by botanists from nearly every civilized country, adopted an *International Code of Botanical Nomenclature* so that there might be uniformity of usage and thereby less confusion in the use of names.

Fig. 3—ARISTOTLE, FATHER OF NATURAL SCIENCE

He wrote books on botany and is credited with having established in Athens the first botanic garden of which there is record

Sometimes plants and plant groups are given a common or a botanical name derived from the Latin or Greek, thus: *Alga,* the Latin name for seaweed, since typical algae are aquatic; *Fungus,* the Latin for mushroom, one of the commonest known fungi. The Greeks called it *sphoggos* (pronounced *sfongos*), because its texture resembled a *sponge; Moss,* from the Latin *muscus.*

Often a descriptive name is applied, such as *Acer.* This is the Latin name for the Maple tree and may have been derived from the Latin adjective *acer* (sharp), referring to the sharp points of the leaves. *Aster* (Latin for star) refers to the shape of the flower of wild asters. *Rhododendron* is from two Greek words meaning *Rose-tree.*

The name may designate the nature of the *place* or the geographical region where the plant grows; thus *Azalea* (Greek, *dry*) referring to the dry habitat of the Azalea known to the Greeks; *Myosotis palustris* (Forget-me-not), the second name being the Latin for *swampy* or *marshy; Iris japonica* (from Japan), and the numerous plants called *americana, canadensis, virginiana,* etc.

It is a common practice for botanists to name a plant after the one who first collected it, or after some botanist or famous man, thus: *Magnolia,* in honor of Pierre Magnol (1638-1715), professor of botany at Montpellier, France; *Nicotiana* (tobacco), from John Nicot, who, while French Ambassador to Portugal, about 1560, sent specimens of the plant to Catherine de Medici; *Sequoia* (the Giant Tree, of California), from a famous Cherokee Indian.

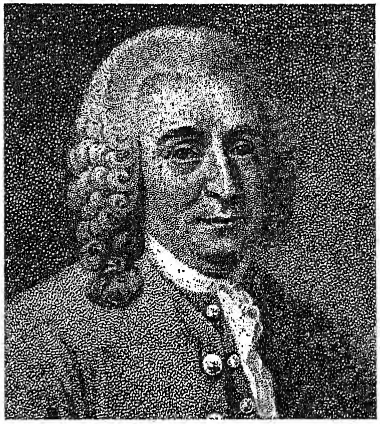


Fig. 4—LINNAEUS, FATHER OF MODERN SYSTEMATIC BOTANY
His *Species Plantarum* is the starting point of modern botanical nomenclature

Why Plants Are Given Latin Names

In order that botanists of different countries may understand each other and be more exact in their language, all plants are given Latin names, for the Latin language is understood in every country. The Latin name for oak is *Quercus.* This is the name of that kind (*genus*) of tree. A genus is composed of one or more species—*e.g.,* White Oak, Scarlet Oak, Post Oak, Pin Oak, etc. They are all *Quercus,* but each has its own second, or species, name. The Red Oak is *Quercus rubra.* That is the

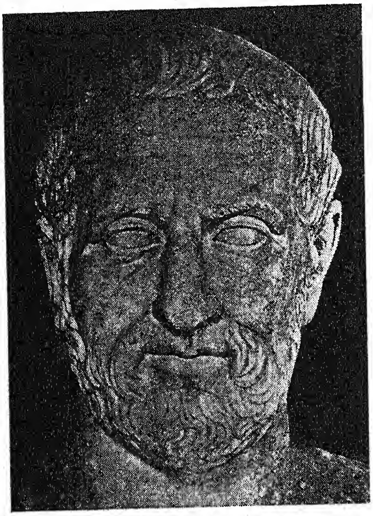


Fig. 5—THEOPHRASTUS

First of real botanists in point of time. He classified plants as trees, shrubs, half-shrubs, and herbs

name of that *special kind* or *species* of oak. This system of naming is called the *binomial system,* because two words suffice to designate the species. This system was in use before the time of the great Swedish father of *systematic botany,* Carolus Linnaeus (1707-1778), but only sporadically. Linnaeus used binomials uniformly and systematically, and their general use dates from the publication of his *Species Plantarum,* in 1753. We can readily understand what a great advantage it is for plants to have the same scientific names in all countries, no matter what other and diverse common names they may have in the various languages of those countries.

The first great task of botany was to describe, classify, and name plants.

CHAPTER V

KINDS OF PLANTS

"SYSTEM is a thread of Ariadne, without which botany is reduced to chaos." Thus, in 1763, wrote Linnaeus. Long before his time botanists had found it necessary to group or classify plants. The earlier systems were naturally crude. Theophrastus (*ca.*372-287 B.C.), pupil of Aristotle, and "first of real botanists in point of time," classified plants into trees, shrubs, half-shrubs, herbs. Leonhard Fuchs (1501-1566), after whom our *Fuchsia* is named, arranged plants alphabetically by their Greek names. The groups of Gaspard Bauhin (1560-1624) were seaweeds, trees, shrubs, grasses, and "lilies." Finally, the modern systems (for there are several) grew out of continued research. The story is too long and technical to be more than referred to here. Modern botanists recognize the following

Great Groups of Plants

1. *Algae*
2. *Fungi* (including Bacteria)
3. *Liverworts*
4. *Mosses*
5. *Ferns* (and their relatives)
6. *Cycad-plants*
7. *Gymnosperms*
8. *Flowering Plants*
   a. with two seed-leaves
   b. with one seed-leaf

In so brief a book as this we can only illustrate each of these various groups by two or three types.

1. Algae

Algae are the most primitive green plants. They live in water (both fresh and salt) or in moist situations. There are four sub-groups—Green, Brown, Red, and Blue-green Algae. All of them possess the green substance *chlorophyll,* but this color is more or less masked by another pigment in the Browns, Reds, and Blue-greens.

Green Algae. The plant body of some of the Green Algae, such as the *Pleurococcus,* which forms a green coating on the

cool, moist sides of tree trunks, fences, and walls, consists of single microscopic cells. They reproduce merely by cell-division. The so-called "Red Snow," which grows on the surface of ice and snow in high latitudes, is a species of Pleurococcus (*P. nivalis*).

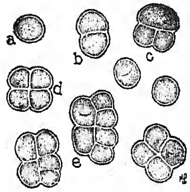


Fig. 6—PLANTS OF PLEUROCOCCUS VIRIDIS

Composed of from one to six cells

Other Green Algae, such, for example, as the Green Silk or "Frog Spittle" (*Spirogyra*), which grows floating (but not attached to anything) in fresh water, consist of filaments of cells that remain attached end to end, after cell-division. They reproduce, not merely by cell-division, but also by cell-fusion (*conjugation*), followed by a *resting period* for the fused body, *zygospore* or *zygote.* After this, cell-division begins again, forming another filament. A resting period is a common feature in the life-history of nearly all plants.

Conjugation is accomplished thus: Two filaments come, by chance, to lie side by side. One or more of the cells of each sends out a small lateral branch. The tips of these branches come into contact, the tubes fuse, and the end walls are dissolved away. Maybe sometime someone will find out how. In one of the cells globules of gas, called *contractile vacules,* appear and disappear in rhythmic pulsation, due to the contraction of their protoplasmic walls. As a result, the protoplasm of this, the *supplying cell* or *gamete,* is forced through the connecting tube into the *receiving cell* or *gamete.* The two gametes then intimately fuse and form a compound cell or *zygote.* This process of *conjuga-*

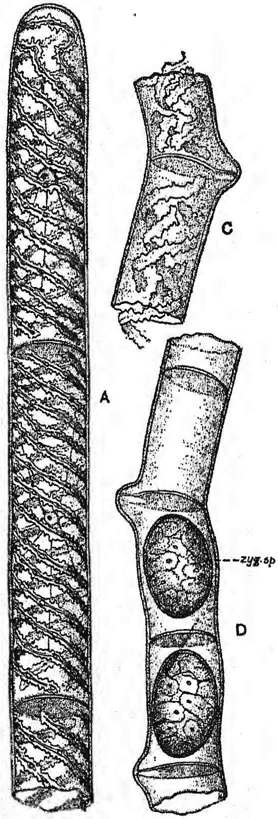


Fig. 7—SPIROGYRA

A, end cells of a filament; D, zygospores (*zygsp*), each formed by the fusing of two adjacent cells (lateral conjugation); C, adjacent cells preparing for lateral conjugation. (Compare Fig. 8.)

tion, though observed for many years, was first accurately described (as to the vacuoles) and photographed by motion pictures about 1924 by Professor F. E. Lloyd, of McGill University, Montreal, Canada.

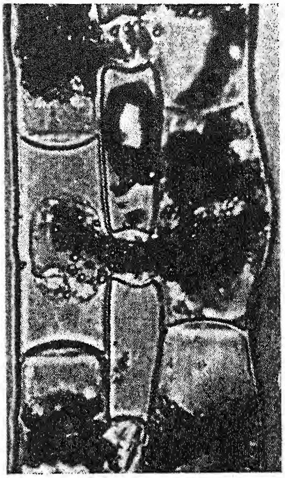


Fig. 8—SPIROGYRA

Cells of adjacent filaments conjugating to form a reproductive spore. The open circular areas are contractile vacuoles which, by their alternate contraction and expansion, assist in the passage of one protoplast through the conjugation tube to unite with the other protoplast. This is Scalariform, or ladder-like conjugation. (Compare Fig. 7.)

Photograph taken through the compound microscope by Prof. F. E. Lloyd

Brown Algae. The Giant Kelps, forming submerged "Kelp Groves" in the ocean off the Pacific Coast of North America, may be noted as representing the *Brown Algae*. They are among the largest known plants. Specimens over 100 feet long have been reported. They are found in other localities also, and, being rich in potash, they are very valuable for fertilizing. Species of *Fucus* and *Ascophyllum,* common on rocks between low and high tide along the Atlantic coast, are used to pack oysters and clams for shipment.

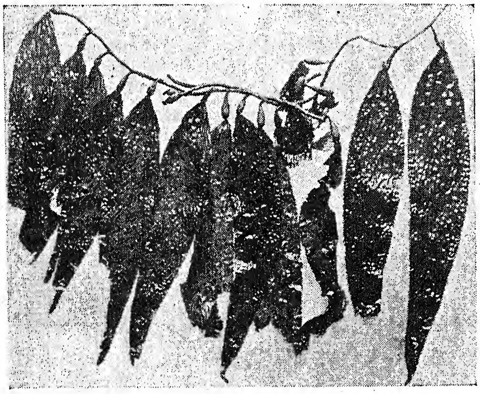


Fig. 9—BRANCH OF KELP, ONE OF THE BROWN ALGAE

The leaf-like structures are not true leaves

Red Algae. Nearly all species grow in the ocean attached to the substratum. The Thread-weed (*Nemalion*) is the best known.

Blue-Green. These are among the very simplest plants that contain chlorophyll. While the Red and Brown Algae reproduce by both cell-division and cell-fusion, the Blue-greens reproduce, so far as is known, only by cell-division.

Sex in Plants

Reproduction that involves only cell-division is *asexual,* and reproduction that involves cell-fusion is *sexual.* Both types are

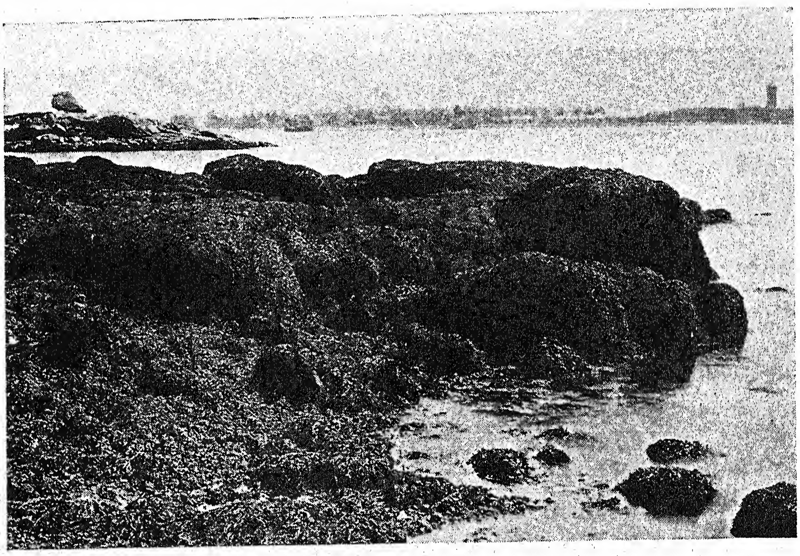


Fig. 10—BROWN SEAWEEDS (*Ascophyllum* and *Fucus*)
Growing on rocks on the seacoast of Hunter's Island New York
Photograph by M. A. Howe

found in plants of all the great groups. *Vegetative propagation*—as when geraniums are reproduced by "slips," roses by "budding" or by "cuttings," potatoes by planting tubers which are modified stems—is a type of asexual reproduction. That plants have sex was first clearly demonstrated in 1694 by the German botanist, Rudolf Jakob Camerarius, in connection with flowering plants.

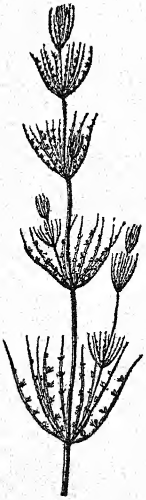


Fig. 11—CHARA, A ROCK-BUILDING GREEN ALGA

(*After Strasburger*)

Plants That Make Rocks

Some of the Green and Brown marine Algae remove from sea-water quantities of calcium carbonate (the substance of which limestone is made),

secreting it and building with it an external coating for themselves much resembling coral formations. These algae are found from the tropics nearly to the poles, and take an active part in building coral reefs. Thus, the atoll of Funafuti, in the South Seas, originally believed to be a typical coral reef (*i.e.,* formed by coral *animals*), was, in 1904, found to have scarcely any coral, but to be composed chiefly of these stone-like algae. They are one of the most important agents in the formation of the atolls and reefs in the Indian Ocean and near the Dutch East Indies. These algae are known to form thick layers on the ocean floor in Arctic waters, and are thus recognized as important agents in the formation of future rock-strata. Much of the limestone in the ancient (*Paleozoic*) rocks of the Rocky Mountains is of algal origin.

Fig. 12—CAMERARIUS

First to demonstrate that plants have sex and that pollination is necessary for seed-formation

One genus of fresh-water Green Algae, *Chara* (commonly called "Stonewort"), secretes so much calcium carbonate from the water as to feel rough and "stony." In 1930 it was reported that these plants, in a small lake in Wisconsin, take from solution in the water nearly 100,000 tons of carbonate in one year. Nearly 40 percent of their bodies is calcium carbonate. This falls to the bottom of the lake each year and thus gradually builds up a layer of limestone. The calcareous marls and tufa in the basin of the now extinct Lake Lahontan, Nevada, and in other places, have been formed by algae, chiefly *Chara.*

2. Fungi

Fungi may vary from single-celled microscopic forms, such as Yeast, to the Giant Puff-balls which are one foot or more in diameter. The late Professor Charles E. Bessey, of the University of Nebraska, reported a Giant Puff-ball measuring over five feet in diameter. Fungi are one of the most important groups of plants. Some of them, like the Puff-balls and mush-

rooms, are excellent food; others (*e.g.*, the toadstools) are deadly poisonous. It has been suggested that the word toadstool may have been derived from the German words, *Todt* (death)

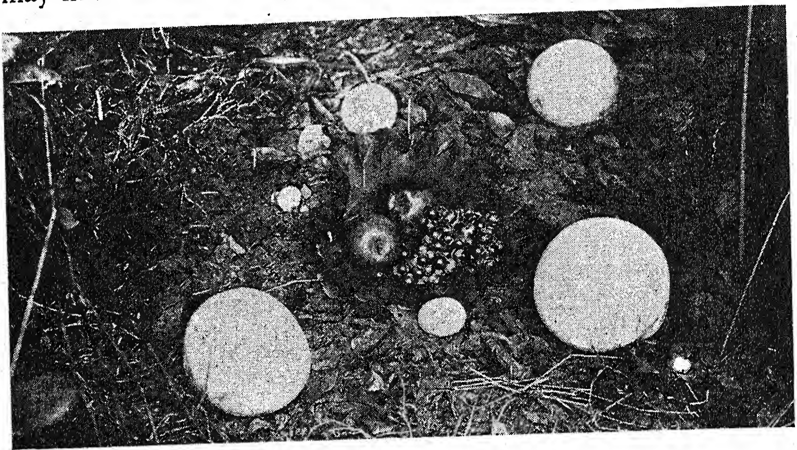


Fig. 13—GIANT PUFF-BALLS (*Lycoperdon giganteum*)
In the center is an egg and some fruit
Photograph by W. A. Murrill

plus *Stuhl* (stool). Philologists do not support this derivation, but derive the word from the early modern English word, *todestoole* or *toadestoole*. There is a similar combination in "Toad-flax" (*Linaria vulgaris*), a flowering plant, also known as "Butter-and-Eggs."

Toadstools and Mushrooms

Mushrooms and Toadstools are not separate forms botanically, and there is no earmark by which the amateur mycophagist may distinguish the poisonous forms from the edible. It is, therefore, never safe to eat fungi collected in the field unless one is able to determine their exact species. The stalk of the edible mushroom (*Agaricus campestris*) supports a cap on the underside of which are thin pinkish *gills* radiating from the stalk to the edge of the cap. The surfaces of these gills are covered with reproductive bodies known as *spores*. When ripe, the spores are wafted away by the wind, fall to the ground, and produce other mushrooms.

The deadly *Amanita* (Fig. 15), responsible for most deaths from "mushroom" poisoning, has white gills and spores, always

has a *cup* at the base of its stalk, and rarely, if ever, grows in the woods. The Czar Alexis, father of Peter the Great, lost

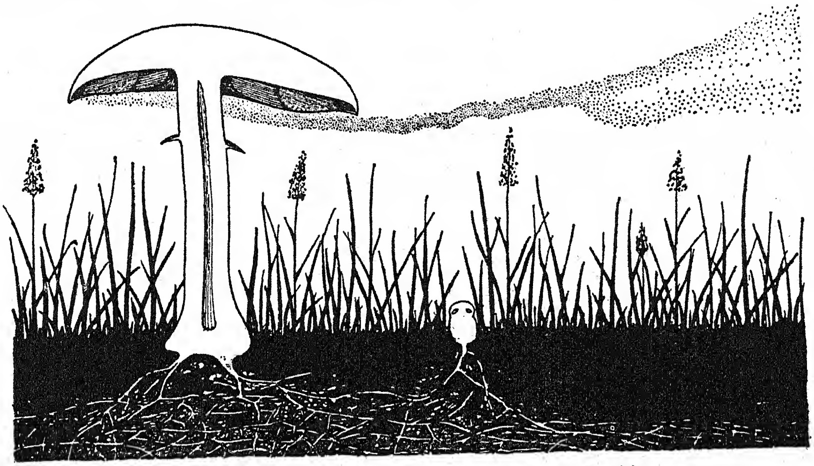


Fig. 14—FIELD MUSHROOM (*Agaricus arvensis*)
Showing liberation of spores, wafted away by a slight breeze; also the underground mycelium. (*After Buller*)

his life in 1676 by eating this fungus. Instead of gills, some fleshy fungi have teeth hanging down, or a surface filled with tiny holes, each of which is the end of a tiny tube in which the spores are produced.

Fig. 15.—THE DEADLY AMANITA
(*Amanita phalloides*)
At the base of the stem note the cup, not present in the edible meadow mushroom
Photograph by Miss E. M. Kittridge

Fungi and Plant Diseases

There are three great menaces to plants: drought, insect pests, and plant diseases. Most plant diseases are "germ" diseases, caused by bacteria or fungi growing on trees, shrubs, ornamentals, and crop-plants. Among bacterial plant diseases are "soft rot" of Calla-lilies, "wilt" of Cucumbers

and Melons, "wilt" of Sweet Corn, and "crown gall," a cancerous-like disease common to Willows, Grapes, Roses, and other plants, especially those related to the Rose, such as Apples, Peaches, and Raspberries.

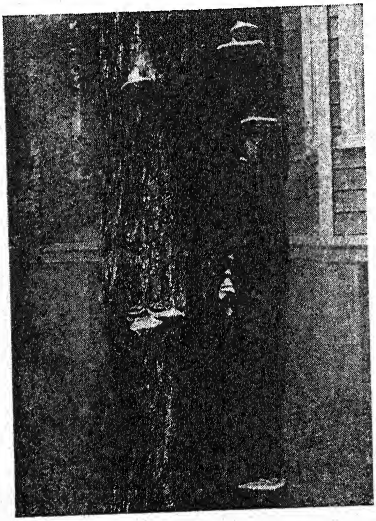


Fig. 16—A SHELF-FUNGUS
(Fomes aplanatus)
On a sugar maple

Diseases caused by fungi are among the most destructive of all. Everyone has seen toad-stools and "shelf-fungi" growing on trees. These are the fruiting bodies of fungi whose absorbing and feeding organs have been growing on the living tissue of the tree-trunk and branches, causing the tree to decay. Spores blown from these fruiting bodies lodge on freshly exposed moist surfaces, as where limbs have been cut or broken off. There they germinate, and exude a liquid called an *enzyme* that dissolves the woody tissue, making it so soft that the delicate filaments of the fungus can grow into it, absorbing parts of it as food, and so ramifying throughout the tree, until some of the threads come to the surface and develop the fruiting bodies. Thus we see why it is important, as soon as a limb or branch is cut off, to paint the fresh surface. This makes it difficult or impossible for fungus "germs" to find a suitable condition for germinating, and so the tree is protected.

Tree Diseases

Among tree diseases one of the most destructive is the Chestnut Blight, which was first observed on park trees in the City of New York about 1904. From there it has spread until it has destroyed practically every Chestnut tree within a radius of several hundred miles of New York, entailing a loss estimated at not less than $25,000,000.

In this tree disease the fungal threads grow under the bark, so that spraying the trees with poisonous solutions

does little or no good. The only remedy will be found in producing, by artificial breeding, a tree that is immune to this disease, just as some people are immune to certain human germ diseases.

The White Pine Blister Rust is caused by a fungus that cannot survive unless it can grow on a currant or gooseberry bush and a pine tree *alternately*. This disease, threatening a total stand of White Pine timber having a value in excess of $400,000,000, can be checked by destroying all the currant and gooseberry bushes in all States where White Pines occur.

Courtesy U. S. Dept. of Agriculture

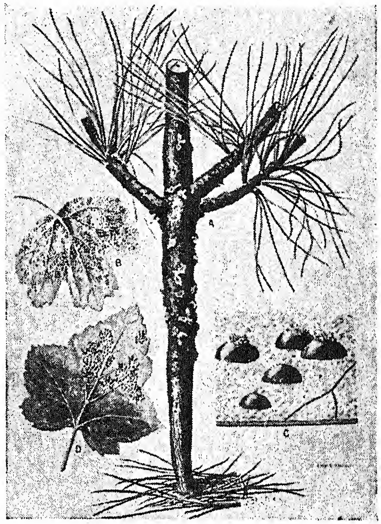


Fig. 17—WHITE PINE BLISTER RUST

A branch of pine with blisters (fruiting bodies of the rust fungus); B, leaf of currant showing early stage; C, part of B enlarged; D, black currant leaf showing late stage, which is transmitted to the pine trees

(After Perley Spaulding)

Smuts and Rusts

Among the most destructive crop diseases are the Rusts and Smuts of Wheat and other cereal grains. The Stem Rust of Wheat, like the White Pine Blister Rust, lives on two different kinds of plants, the wheat and the barberry, passing alternately from one to the other. Therefore, measures of control involve the destruction of barberry bushes in the neighborhood of wheat fields. Buller calculated that one barberry bush of two hundred leaves, on which the fungus was fruiting, would produce as many as a hundred million spores to be blown by the wind to fields of wheat. We can thus realize how rapidly it can spread and how difficult it is to control. At first it was not recognized that the organism on the grain and that on the barberry are only different phases in the life-history of the same plant.

The Smuts are so called because their spores occur as a dark brown or black powdery mass. They are easily blown about by the wind. They germinate on the flower, producing a fungus filament that grows down into the developing seed where it remains dormant, until the seed, when planted, germinates. The fun-

gus threads then continue to grow up through the tissues of the plant until it begins to flower. They then grow into the floral parts and completely destroy them while producing the next crop of spores.

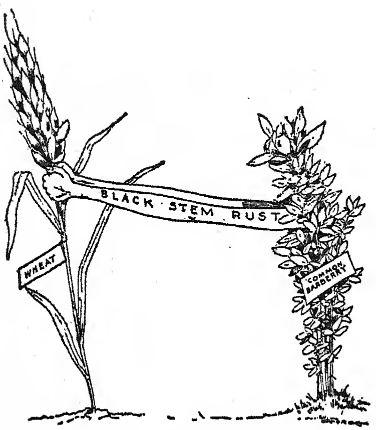


Fig. 18—CARTOON
Illustrating the life history of the wheat rust, a fungus parasite having two hosts. To get rid of the wheat rust it is necessary to destroy all nearby bushes of the common barberry

Courtesy U. S. Dept. Agriculture

There is not space here to more than mention other disease-causing fungi, such as Stinking Smut of Wheat, Loose Smut of Oats, Covered Smut of Barley, Corn Smut. These *pathogenes* cause annual losses of many millions of bushels of grain, cause the farmer no end of trouble as well as financial loss, and help to increase the cost of each loaf of bread. In fact, the bulk of our food supply would fail us if we did not keep these disease-causing fungi in check. The drug ergot (*Clariceps purpurea*) is derived from a sac-fungus parasitic on rye and other grasses.

Why Things Get Moldy

Fungi reproduce both by cell-division and cell-fusion. Yeast cells give off tiny buds, bacteria reproduce by continuous cell-division and also by the transformation of the protoplasm (within the cell-wall) into a number of spores. Bread-mold is a type of thread-like or filamentous fungus. The threads are called *hyphae,* and a mass of them *mycelium.* Special hyphae bear *spore-cases* at their tips, and the protoplasm in these spore-cases divides and sub-divides into myriads of spores, which are scattered by the wind when the spore-case breaks open. Such spores, together with fungi and yeast cells, are widely disseminated in the air at nearly all times, and are constantly falling on surfaces of objects. Thus it is that a piece of moist bread if merely left exposed to the air, will in a few hours show a growth of Bread-mold on its surface, although no one has deliberately placed any spores there. Perhaps they were on the

fingers and thus unconsciously transferred to the bread when it was handled.

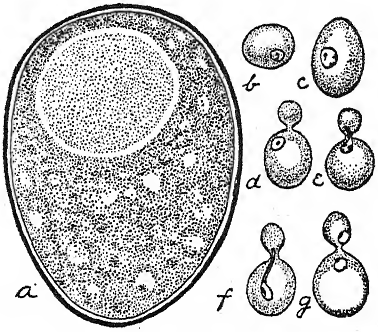


Fig. 19—YEAST PLANTS
Some of them budding

Bread-mold and other filamentous forms of fungi also reproduce by cell-fusion. In 1904 Dr. A. F. Blakeslee, now of the Carnegie Institution of Washington, discovered that there are two strains of bread-mold, plus (+) and minus (—), corresponding to male and female. When these grow side by side branches from each meet at the tips and the terminal bits of protoplasm unite to form a *fusion-spore,* which may germinate and reproduce a new lot of mycelium.

On account of close resemblances between fungi and algae, both as to structure and methods of reproduction, it is thought by many botanists that the fungi were, in the course of ages, derived by descent from the algae, the process involving a loss of the chlorophyll, thus making it necessary for the fungi to live on living or dead organic matter.

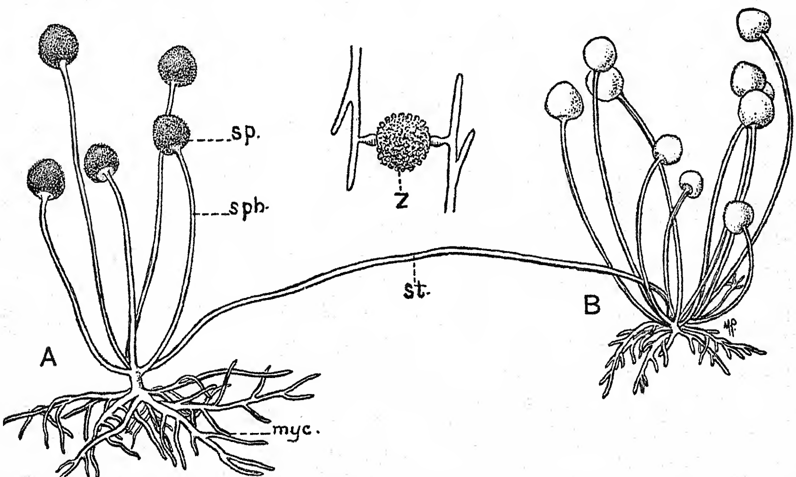


Fig. 20—THE BREAD-MOLD FUNGUS (*Mucor*)

A, older plant; B, newer plant, reproduced at the tip of the runner or stolon (*st*); Z, zygospore, formed by the fusion of protoplasm from two adjacent plants; *sp,* spore-case; *sph,* stalk of same; *myc,* mycelium

Fig. 21—PASTEUR

He founded the science of bacteriology and disproved the doctrine of spontaneous generation

Bacteria

Bacteria, often called "germs" or "microbes," were first seen and described in 1687 by Antonius van Leeuwenhoek* a Dutch naturalist who made pioneer studies with the microscope. The science of bacteriology was developed by Louis Pasteur (1822-1895) of France, who was one of the first to establish both the relation between bacteria and disease and their rôle in certain commercial processes, such as the making and aging of beer and wine. The term "pasteurizing," applied to a process of killing bacteria by heat, is derived from his name. Some time ago the people of France voted for Pasteur as the greatest Frenchman of all time.

Making Bread with Bacteria

Not many years ago "milk emptins" or "salt rising" bread was often made by the wives of American farmers. An uncovered mixture of fresh milk and corn meal was set aside over night in a warm place. "Wild" bacteria got into this from the air or the surfaces of the utensils used, and thus the mixture became a liquid leaven. Mixed with the dough it would cause the dough to "rise." No commercial yeast was put in. The "Children of Israel" were not so fortunate when they fled from Egypt. Leaving in haste, they were either careless or forgetful about taking with them the "leaven" or dough saved from previous bread makings. As a result, they had only "unleavened" bread for a time, hence the custom of eating unleavened bread at the feast of the Passover (Exodus XII, 34-39). Commercial yeast must originally have been derived from a wild form of yeast captured and cultivated, possibly by prehistoric man.

* Pronounced Lā′-vĕn-ho͝ok.

3. Liverworts

Liverworts are so called because of a fancied resemblance between their shape and the lobed liver. Their plant body is a flat, green, leaf-like *thallus*. Some of them live on land and some on water. Many of them bear little cups on their upper surface in which tiny buds or *gemmae* are formed. Thus they are reproduced asexually. They also have upright branches bearing small bottle-shaped organs (*archegonia*) in each of which is developed a large *egg-cell,* and other branches bearing small club-shaped organs (*antheridia*) in each of which many free-swimming *sperms* develop.

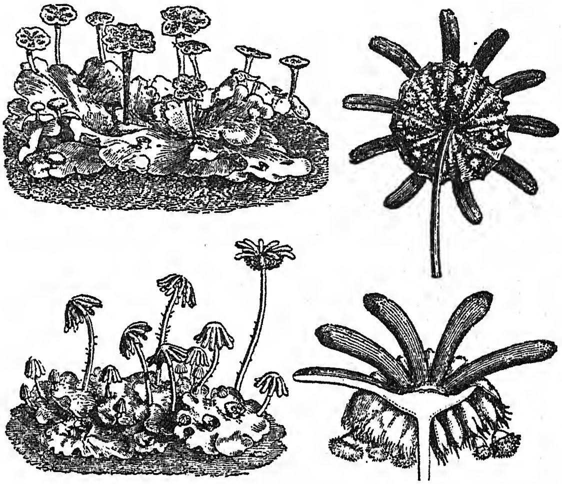


Fig. 22—A LIVERWORT (*Marchantia*)
Above, at left, a male plant, with branches bearing antheridia; below, a female plant with branches bearing archegonia; at the right, tops of female branches bearing spore-producing organs
(*After Baillon*)

When sperms escape from an antheridium they swim in films of water, supplied by dew or rain, until they reach an archegonium. They enter the *neck-canal* of the archegonium and swim down to the egg-cell which they enter, and the two bodies (egg and sperm) fuse together. The process is call *fertilization.* In conjugation, the fusing cells are of similar size and structure; in fertilization, of unlike size and structure. The *fertilized* egg now develops into a stalk fastened to the parent plant and bearing a spore-case at its tip. After the spores are ripe they are scattered by the wind. When they fall on suitable surfaces they may germinate, thus producing other *thalloid* liverworts like the one from which they came. The series of processes from fertilized egg to fertilized egg, or from spores to spores again, is called the *life-cycle.*

4. Mosses

Mosses are more highly organized than Liverworts. When a moss spore germinates it produces a branched green filament resembling one of the filamentous green algae. Shortly one or more leafy buds appear on this green thread and develop further into leafy stems, which produce root-like organs (*rhizoids*, but not true roots) at their lower ends. Some of the plants among the leaves at their tips, produce archegonia which bear eggs, and others, antheridia which bear sperms. As in the case of the Liverworts, the sperms finally fertilize the eggs, which then develop delicate stalks that grow upright from the tips of the leafy moss-plants. Spore-cases full of green-colored spores are formed at the upper end of the stalks. When the ripe spores are scattered they may germinate on suitable, moist surfaces, producing the tiny green thread again, and thus initiating another life-cycle. In some mosses the antheridia and archegonia are borne on the same plant; that is, the plants are *monoecious* (of one household). When the antheridia and archegonia are on different individuals the plants are *dioecious* (of two households).

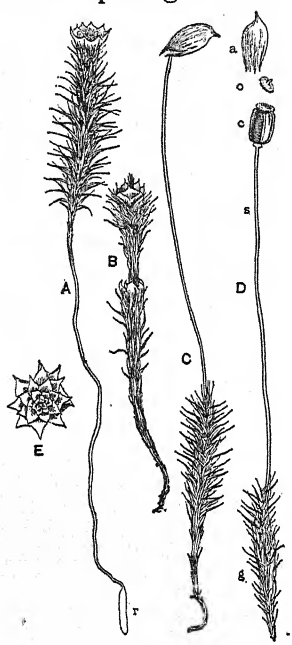


Fig. 23—MOSS-PLANTS
A and B, male; C and D, female;
E, tip of male plant

Fig. 24—PLANT OF CINNAMON FERN
With spore-bearing leaves (center), surrounded by green vegetative leaves

5. FERNS

The life history of ferns remained a mystery until it was discovered and described by the German botanist, Wilhelm Friedrich Benedict Hofmeister, in 1841, and by the Polish botanist, Leszczyc Suminski, in 1848. The fern-plants, as we know them, produce clusters of spore-cases on the under sides of some or all of their leaves. Spore-bearing leaves (*fronds*) are *sporophylls.* When the spores are scattered and germinate, they do not at once produce another fern-plant, but a tiny green *prothallus,* resembling a small liverwort. The prothallus bears antheridia with sperms and archegonia with eggs. The fertilized egg develops a fern-plant like the one with which we started. It is at first parasitic on the prothallus, but finally becomes established in the soil and the prothallus dies. In the life-cycle of a plant, the form that bears spores is the *sporophyte* (spore-plant); the form that bears the eggs and sperms is the *gametophyte* (gamete-plant), because eggs and sperms are both called *gametes* (the bodies that fuse). The change from gametophyte generation to sporophyte generation and back again, in the

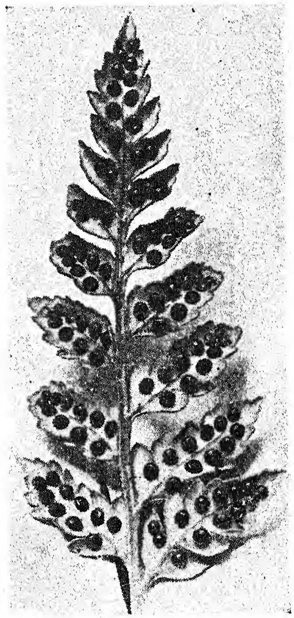


Fig. 25—PART OF SPORE-BEARING LEAF OF A FERN (*Polysticum*)

The globular structures (on the under side) are groups of spore-bearing organs

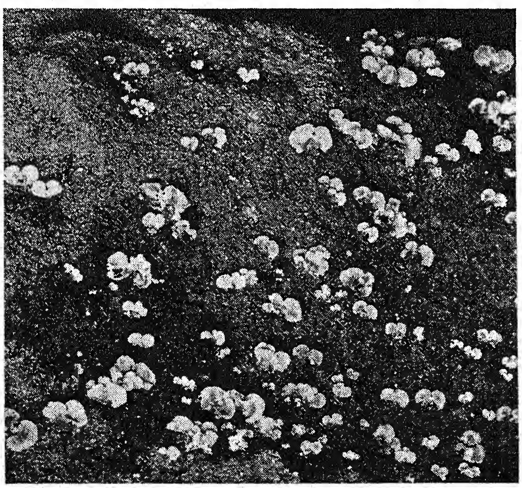


Fig. 26—FERN PROTHALLIA GROWING ON A ROCK

life-cycle, is called *alternation of generations.* This phenomenon may be traced in all the great groups of plants. Flowering plants, both herbaceous forms and trees and shrubs, are sporophytes.

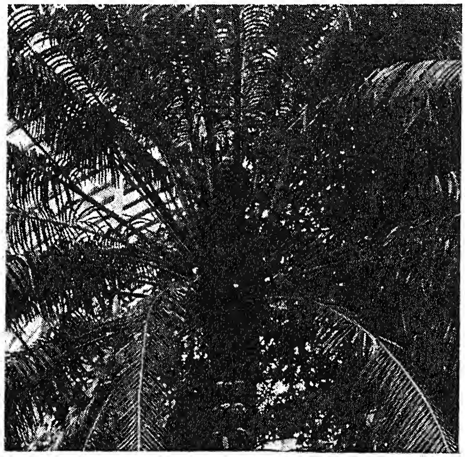


Fig. 27—A CYCAD—"SAGO PALM"
Note the large seed-bearing cone at the apex of the stem

6. Cycad-plants

We now come to the first group of plants that bear seeds. If the plant which develops from the fertilized egg-cell of the fern should cease growth after it had made a tiny stem and one or a few leaves, and should, in the meantime, become enclosed in the structures that contain it, we should have a resting *embryo-plant.* This embryo and the envelopes enclosing it would be a seed—for that is what a seed is. When seeds are planted, after a longer or shorter rest period, the embryo resumes its growth, and this is called the *germination of the seed*—a very different process from the germination of a spore, just as the seed is a very different structure from a spore.

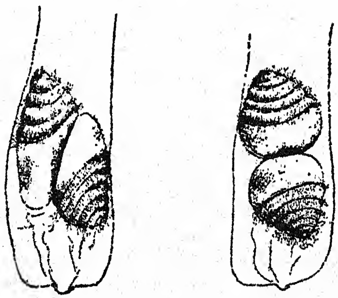
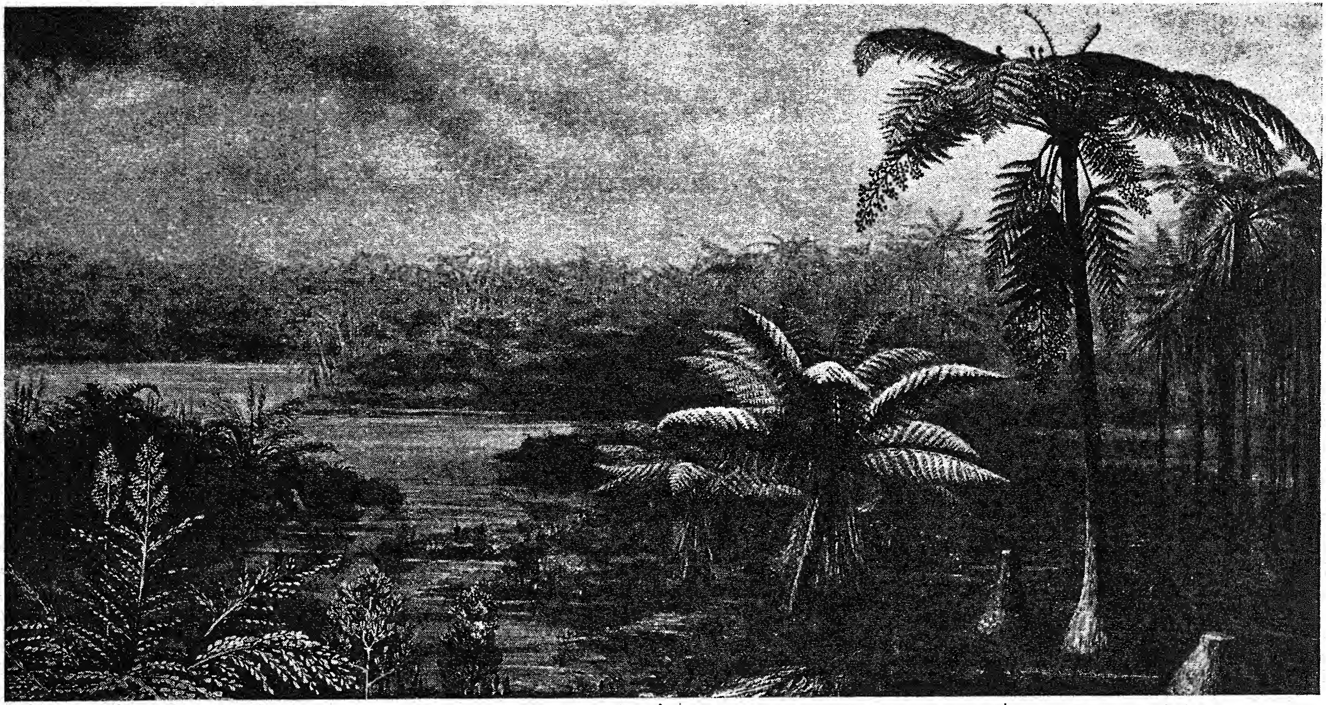


Fig. 28—TIPS OF POLLEN-TUBES OF A CYCAD (*Zamia*)
Each containing two motile sperms that swim by means of their cilia
(*After H. J. Webber*)

In earlier geological ages there were seed-bearing ferns, as we know from their fossil remains, but these forms gradually died out.

Cycads are the most primitive living plants that bear seeds; they appear to be descended from ancestors which had both fern-like and cycad-like characters, and which are therefore called Cycad-ferns. They are known to us, of course, only by fossils.



ARCHAEOPTERIS DEVONIAN | STAUROPTERIS CARBONIFEROUS | PECOPTERIS CARBONIFEROUS-PERMIAN | EOSPERMATOPTERIS DEVONIAN

Fig. 29—IMAGINARY LANDSCAPE OF PREVIOUS GEOLOGICAL AGES

Showing some of the ancestors (reconstructed) of modern ferns

Designed and drawn by Maud H. Purdy, under the supervision of Dr. Alfred Gundersen

What Is a Seed?

The *Sago palm,* known outside the sub-tropics only by conservatory specimens, is a typical Cycad. Botanically, it is not a palm, and not even related to the palms. In addition to foliage-leaves, Cycads have leaves that bear relatively small spores, and other leaves that bear *ovules* containing relatively large spores. The large spores remain in their spore cases and develop into female gametophytes which live as parasites on the cycad-sporophyte.

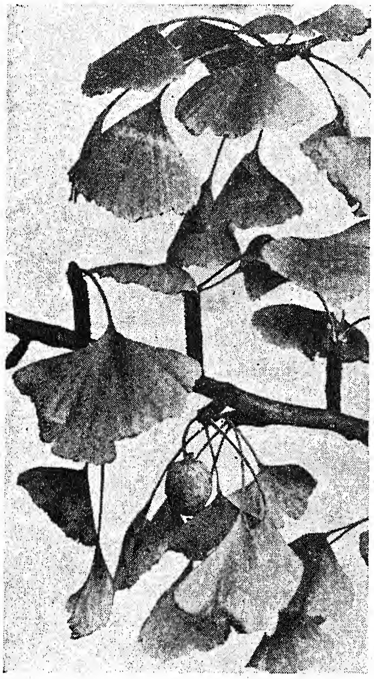


Fig. 30—BRANCH OF MAIDENHAIR TREE (*Ginkgo*)

Bearing one fruit

The small spores undergo cell-division inside their cell-walls, and two of the resulting cells become sperms, which can swim vigorously in liquid. At this stage the small spores are called *pollen-grains.* They are carried away by the wind, and some of them, by chance, lodge in a *pollen-chamber* of the ovule. Here they germinate, each sending out a *pollen-tube* that grows down to an archegonium in the ovule. The sperms then become free from the pollen-tube and, by means of many fine *cilia,* each swims down into an archegonium until it reaches the egg-cell with which it fuses, thus accomplishing fertilization. The fertilized egg-cell then develops a tiny embryo-cycad, which remains for a time at rest in the tissue of the ovule. This whole structure, with the envelopes that enclose it, is a seed. Until the above facts are clearly grasped one cannot really understand what a seed is. After a rest-period, the seed, if planted, will germinate—that is, the embryo will begin to grow again, sending out roots from one end of its embryo-stem and leaves from the other end—and

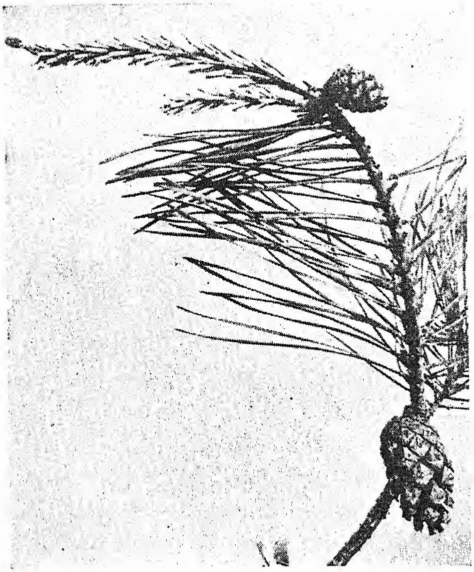


Fig. 31—BRANCH OF SCOTCH PINE
(*Pinus sylvestris*)
Showing young seed-bearing cone at tip, one-year-old cone (middle) and two-year-old cone

thus a new cycad-plant is started.

The *Maidenhair Tree* or *Ginkgo* is related to the Cycads, having motile* sperms in its pollen-tube. This tree is a strictly cultivated plant, no specimen ever having been found growing wild in modern times. It has been preserved for centuries by cultivation in the temple gardens of Japan.

7. Gymnosperms

This group includes our cone-bearing evergreens, such as the Pines, Hemlocks, Cypress, California Big Tree (*Sequoia gigantea*), and others, and their relatives, such as the American Yew or Ground Hemlock, the English Yew, and the Juniper. The group to which the pines belong are *Conifers*, that is, they bear their seeds in *cones*, while the Junipers and Yews bear their seeds in a berry-like fruit.

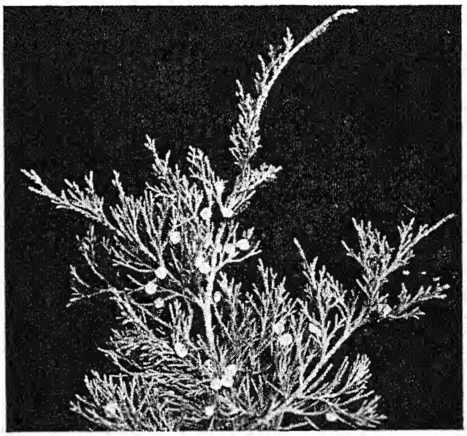


Fig. 32—BRANCH OF VIRGINIA JUNIPER
Showing berry-like fruit

Pollen from the male cones of the pine is blown away by the wind, and some of it lodges on the surface of the ovules between the scales of the seed-bearing cone, where it germinates. The vari-

* Motile, capable of, or exhibiting, spontaneous movement.

ous steps leading to seed-formation are quite similar in details to those in the Cycad, except that the sperm-cells are not motile and so must be carried to the egg-cell by means external to themselves.

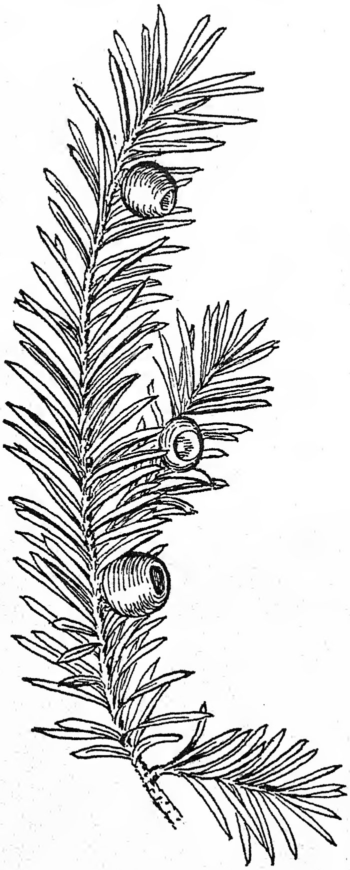


Fig. 33—BRANCH OF AMERICAN YEW
(*Taxus canadensis*)
Showing berry-like fruit, red in nature

8. Flowering Plants

Flowering Plants comprise the group which most people have in mind when they think of plants; it is the group in which most persons are interested. It would require several books to describe all the various kinds of flowering plants. The great *Prodomus* (Introduction) of DeCandolle, *briefly* (!) describing the known species of Dicotyledons only, occupies sixteen volumes of 500 to 1200 pages each. All flowering plants fall naturally into one or two groups, according to whether their embryos have two *cotyledons* or seed-leaves (*Dicotyledons*), like Beans, or one seed-leaf (Monocotyledons), like Corn.

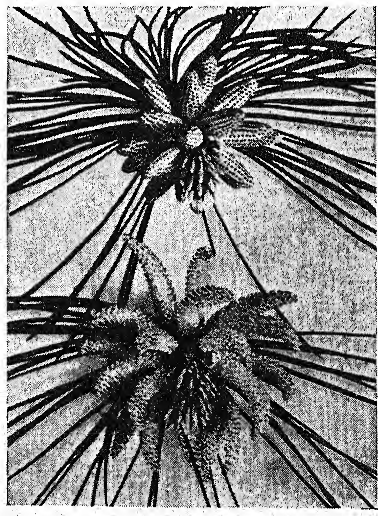


Fig. 34—POLLEN-BEARING CONES OF AUSTRIAN PINE
Above, ripe; below, most of the pollen scattered

Monocotyledons were at one time thought to be more primi-

tive than dicotyledons. Studies of plant embryos, however, have disclosed the fact that the embryos of many monocotyledons have the rudiment of a second seed-leaf or cotyledon. In some cases, this rudiment develops into a more or less perfect cotyledon, thus producing, as a "sport," a dicotyledonous seed. A few monocotyledonous plants habitually have embryos with two seed-leaves, although they possess the anatomical and flower characters of monocotyledons. They are "dicotyledonous monocotyledons."

Fig. 35—PINE TREE SHEDDING A DENSE CLOUD OF POLLEN WHEN SHAKEN BY THE WIND

In other studies embryos of dicotyledonous plants have been found with one cotyledon partially or wholly undeveloped, as a "sport" or exceptional deviation from the normal. They have been called "monocotyledonous dicotyledons." These and other studies suggest that plants with two cotyledons may have appeared before those with only one. However, the number of cotyledons alone does not determine a plant as a monocotyledon or a dicotyledon, but its whole make-up, including the structure of the flower and the anatomy of the root, stem, and leaves.

Monocotyledons give us the most important food plants of the world, including all the cereal grains (wheat, rice, Indian corn, barley, rye, oats, etc.), cocoanut and date palms, bananas, and the meadow grasses furnishing fodder for farm animals. They also give us such flowers as Iris, Lilies, Tulips, and Orchids.

Dicotyledons give us such important food plants as potatoes, most "vegetables" (cabbages, turnips, lettuce, carrots, peas, beans, etc.) and fruits (apples, oranges, lemons, berries, plums, peaches, pears, etc.) and such flowers as Peonies, Roses, Sweet Peas, Rhododendrons, Chrysanthemums, Asters, and Dahlias.

CHAPTER VI

SELFISH ACTIVITIES OF PLANTS

IN DISCUSSING the first seven groups of plants we have emphasized their ways of reproduction—functioning for the race to which they belong. But each plant must also function for itself, that is, it must feed, drink, keep adjusted to its surroundings, and keep healthy if it is to produce an abundance of healthy offspring. It will be an advantage to discuss these "selfish" (or so-called "vegetative") activities before considering the means of reproduction of flowering plants.

HOW PLANTS FEED

Animals eat plants, and some plants feed on other plants; in fact, all food is organic. Organic matter is made from inorganic. Neither plants nor animals can feed on the inorganic chemical elements and compounds that compose the soil and air.

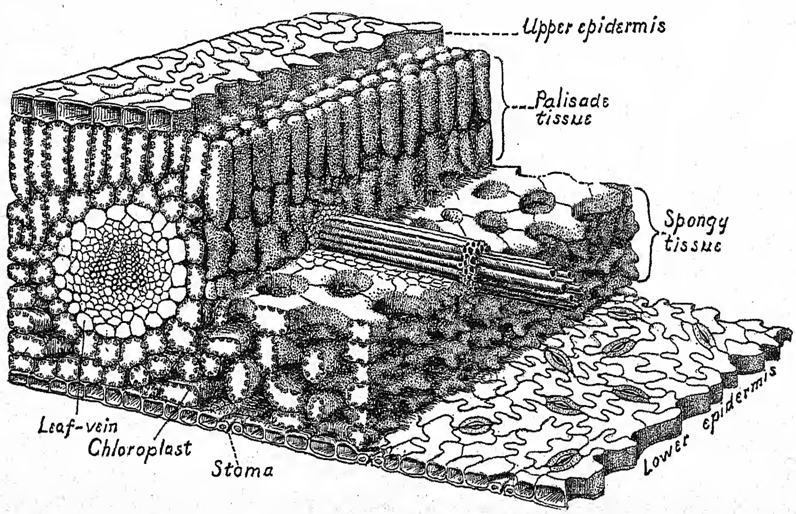


Fig. 36—PORTION OF A GREEN LEAF VERY HIGHLY MAGNIFIED, SHOWING THE CELLULAR STRUCTURE

Modified from Transeau's General Botany

These materials must first be transformed into organic compounds before they can serve as food. To do this is the main function of leaves. Everything about a leaf—its shape, structure, color, position on the plant—has meaning only when we understand that its chief function is the manufacture of food for the plant that bears it.

Why Leaves Are Green

The only mechanism known by which inorganic matter can be converted into (organic) plant food is the green chlorophyll (see page 3). It is a very complex colloidal substance, full of electric energy, and occurs in the cells of leaves or other green parts of plants as tiny bodies called *chloroplasts.* It is usually accompanied by two yellow pigments, *carotin* (abundant in carrots) and *xanthophyll* (leaf-yellow). There are, in reality, two kinds of chlorophyll, chlorophyll *a* and chlorophyll *b.* Compared to a molecule of salt, which contains two atoms ($NaCl$ —sodium and chlorine), a molecule of chlorophyll is an enormous and complex body, containing as many as 136 atoms ($C_{55}H_{70}O_6N_4Mg$ for chlorophyll *a*). The leaf-cells which contain it are arranged in a very definite order inside the leaf, and are protected by a cellular skin or *epidermis* on the upper and lower surfaces of the leaf. The chlorophyll-bearing cells are more closely packed together against the upper epidermis and usually contain more chloroplasts than the more loosely arranged cells near the lower epidermis. That is why most leaves are darker green on the upper side.

The epidermis is perforated by a great number of tiny holes called *stomata,* each of which is surrounded by two *guard-cells.* The guard-cells are the only epidermal cells that contain chlorophyll. Through the stomata there is a constant interchange of gases between the air inside and the air outside. These gases are chiefly oxygen, carbon dioxide, and water-vapor.

Sugar from Air and Water

Through the stem of the leaf there passes the weak watery solution which entered the roots from the soil and passed up the woody part of the stem. This solution contains many chemicals (calcium, potassium, magnesium, phosphorus, sulphur,

iron, nitrogen salts, etc.). In the leaf the carbon dioxide (CO_2) is separated into its components, carbon and oxygen, and the carbon is combined with the water (H_2O) to produce a form of sugar (*e.g.*, dextrose, $C_6H_{12}O_6$), an organic *carbohydrate* substance upon which plants can feed. These transformations are accomplished by chlorophyll, which can act only when sunlight (or artificial light equivalent to sunlight) is shining upon it. The chlorophyll has often been likened to a factory run by the energy of light. There is no other method yet known to science by which carbohydrates can be formed from inorganic compounds. It is called *photosynthesis* (putting together in light). This is one of the most fundamental processes in nature, and is essentially electrical. The colloidal chlorophyll is full of particles bearing electrical charges, the sunlight is electrical, and if one portion of a leaf is illuminated while the remainder is kept dark there is a difference of electrical potential between the two portions. In darkness or subdued light the base of the leaf is electrically positive to the tip.

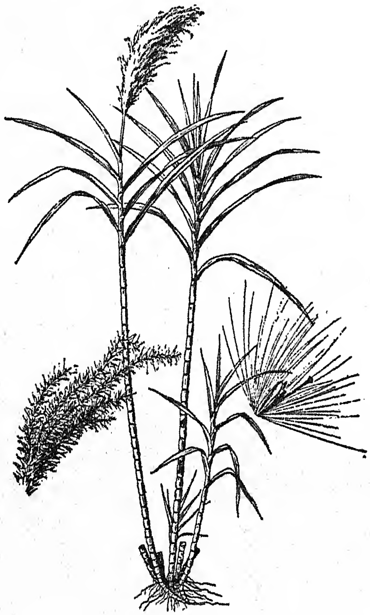


Fig. 37—PLANT OF SUGAR CANE

Much reduced in size. At left, part of flower-cluster; at right a flower

(*After A. S. Hitchcock*)

Courtesy of U. S. Department of Agriculture

"But for the mighty magician chlorophyll, conjuring with sunbeams," said John Fiske, "such things as animal life and conscious intelligence would be impossible; there would be no problems of existence nor philosopher to speculate upon them."

Millions in Leaves

If we keep these thoughts in mind, with what different emotions we behold a large tree bearing thousands of leaves quivering

in the sunlight, especially if we realize the number of cells in which photosynthesis is taking place. If a man should begin the moment he was ten years old to pick, say, a maple leaf to pieces, cell by cell, and should remove one cell every minute, he would not complete the task before he was 100 years old, for there are fully fifty million cells in the leaf. Remember, too, that there are ten or a dozen or more chlorophyll grains in each cell between the upper and lower epidermis. Haberlandt, a German botanist, estimated that in a leaf of the Castor Bean plant there are about 495,000 chloroplasts per square millimeter; that would be over 200,000 in an area (leaf-thick) the size of the period at the end of this sentence.

Sugar Plants Par Excellence

The amount of sugar made by green leaves varies with the external conditions, the kind of plant, and the condition of the plant as to health and vigor. Dr. William Francis Ganong, professor of botany at Smith College, has stated the matter in a way easy to remember. For many plants collectively out of doors, says Professor Ganong, the amount is approximately one twenty-fifth of an ounce per square yard of leaf surface per hour. A leaf suitably exposed will, in a summer, make enough sugar "to cover itself with a solid layer a millimeter (one twenty-fifth of an inch) thick."

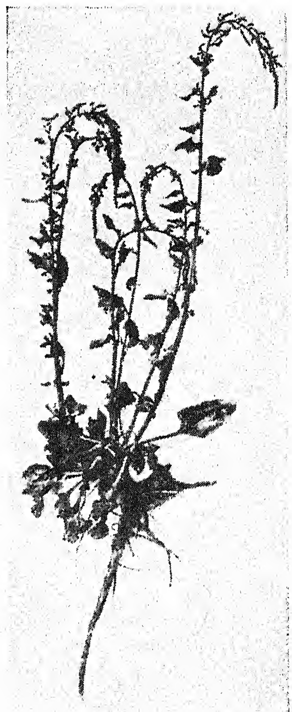


Fig. 38—PLANT OF WILD FORM OF SUGAR BEET

(Compare Fig. 39)

About 13 percent of the total energy of foods eaten by Americans is derived from sugar. Certain plants are "experts," so to speak, at sugar making. Perhaps the one most familiar to us is the Sugar Cane, cultivated extensively in tropical and sub-tropical regions. The Sugar Beet, cultivated in temperate regions, and the Sugar Maple are also important sources of

sugar. Sugar Cane, the main source of cane sugar, grows generally throughout the warm regions of the globe. It has been cultivated in China for 2000 to 3000 years, and probably longer than that in India.

Beet sugar is chemically cane sugar ($C_{12}H_{22}O_{11}$). The

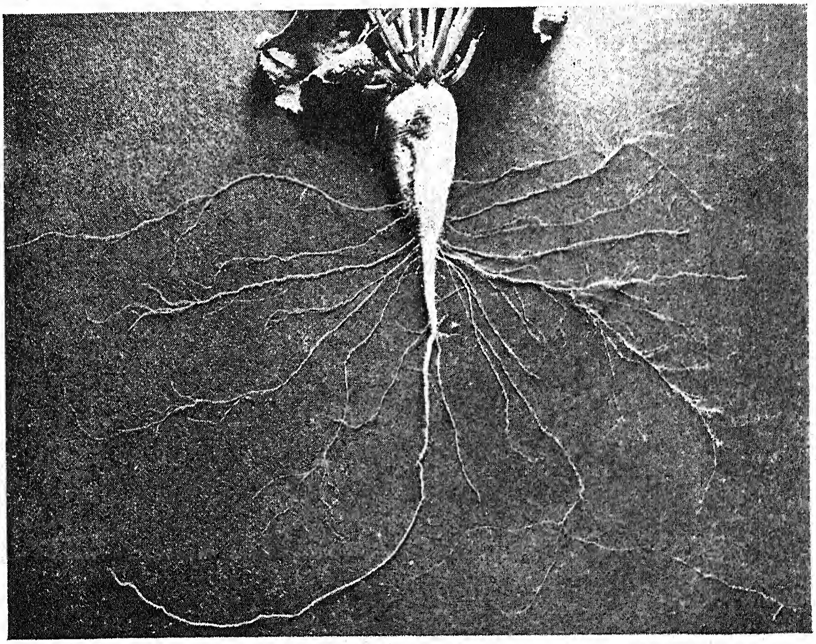


Fig. 39—PART OF PLANT OF CULTIVATED SUGAR BEET

(*Compare Fig.* 38)

breeding of beets for sugar content is noted on page 106. Maple sugar and maple syrup are made by boiling or evaporating the sap of the Sugar Maple (*Acer saccharum*). It is said that this process was taught to the white settlers by the American Indians of western Massachusetts.

Proteins in Leaves

Some people are vegetarians, eating no meat. But meat supplies proteins, and proteins are an essential element in our diet. Vegetarians obtain their protein by eating certain seeds, such as peas, beans, various nuts, and "whole" wheat bread, all of which are rich in plant proteins. It is the protein in flour that makes a tough elastic membrane in dough, so that the gas

produced by the fermentation of the yeast is retained and makes the dough "rise." These proteins are all made in green leaves, and are continually flowing from the leaves through the stems to the developing seeds where they are changed into more stable forms of protein and stored, primarily as food for the embryo in the plant. When these *proteinaceous* parts are eaten by man and the lower animals the plant proteins, like the sugars and starches, are broken down by enzymes in the digestive tract and recombined in the various organs (also by enzymes) into animal tissue—muscle, etc., which is essentially proteinaceous.

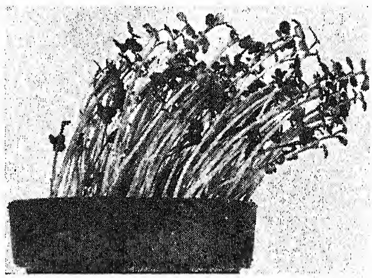


Fig. 40—SEEDLINGS OF WHITE MUSTARD
Turning toward the light which came chiefly from the right side

Sun Worship

How important it is for leaves to be perfectly adjusted to the best (not necessarily the greatest) amount of light! This is accomplished in several ways. In the first place, leaves are not only flat and thin, so as to expose a maximum amount of surface to the light, but they are located at or near the ends of the branches, and are able to alter their position more or less according to the direction of the source of light. Thus when a new length of stem is growing out of the bud in the spring the young leaves twist and turn and bend their stalks in such a way as to reduce the amount by which one leaf shades another, and also to present each leaf surface in a favorable way to the sunlight. It is common for the final pattern of the foliage to adjust itself in such a way as to form a *leaf-mosaic*.

Fig. 41—*BEGONIA SPECULATA*
To show leaf-mosaic

In some plants, such as geraniums, the leaves have a *fixed*

light position which may not be altered, once it has been assumed; others, such as the Nasturtium, are able to change the position of the leaves many times to conform to new *light-directions.* The property of a plant by virtue of which it can detect the *direction* of the source of light is *phototropism.* Certain plants (*e.g.,* Wild Lettuce) growing in the open, customarily place their leaves in a fairly accurate north-south plane, and are consequently called *compass plants.*

The Nervous System of a Leaf

How a leaf can detect the direction and intensity of light was for a long time a mystery. It has been found that the epidermal cells act as lenses, so that photographs may even be taken by means of them. They focus the sunlight so as to make a bright spot on the protoplasm at the opposite side of the cell. Haberlandt suggested that this was the way the leaf perceived, for the spot of light would change its position as the direction of the light rays changed, but Dr. Harold Wager; of England, by careful experiments, was led to doubt this. He thinks the chlorophyll grains afford the mechanism for receiving the stimulus, which is then propagated through the sensitive protoplasm to the leaf-stalk which bends and twists until the leaf is better adjusted to the light. Perhaps we have not yet reached the correct explanation.

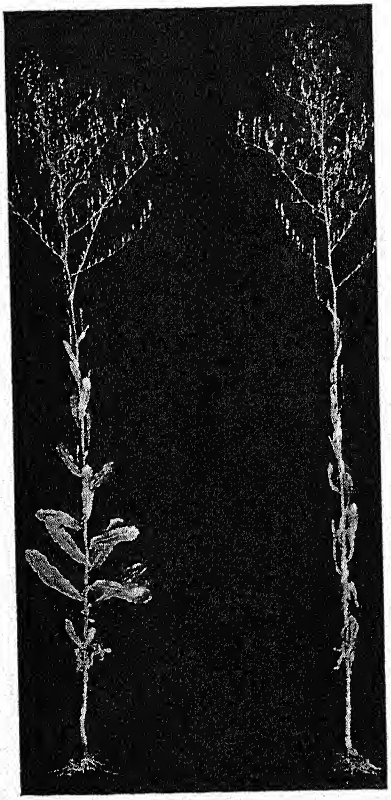


Fig. 42—A "COMPASS-PLANT"—WILD LETTUCE

Two views of the same plant: at the left looking east, and at the right looking north

Why Leaves Do Not Get Hot

Timiriazeff has calculated that if all the light energy ab-

sorbed by a given amount of chlorophyll were converted into heat in the chlorophyll the temperature would rise to 10,832° Fahrenheit, but, although the leaves of grass, trees, and other plants may receive the direct rays of the midsummer sun all day they do not get hot or even appreciably warm.

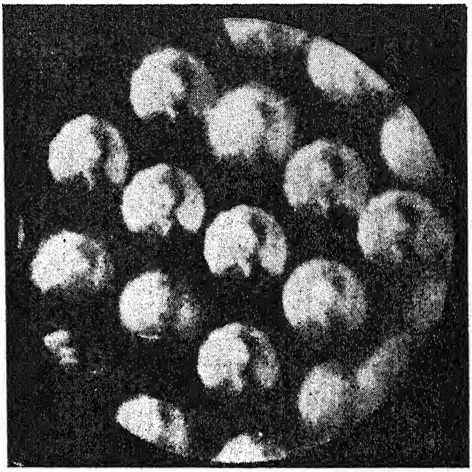


Fig. 43—PHOTOGRAPHS OF A HUMAN FACE TAKEN WITH THE SURFACE CELLS OF A LEAF ACTING AS LENSES
(After Harold Wager)

There are at least three reasons for this. In the first place, about 30 percent of the sun's rays coming to a leaf either pass through it or are reflected. Secondly, at least 50 percent are used to evaporate water within the leaf and from its surface. Only about 1 or 2 percent are used for the work of photosynthesis. Thus only about 18-20 percent are available to raise the temperature of the leaf above that of its surroundings, and this slight rise of temperature occurs only when the surrounding air is so humid that water evaporates only slightly or not at all.

Chlorophyll and Modern Warfare

In the World War it was not uncommon to camouflage a road or other locality by a covering painted green to simulate the adjacent vegetation. This could be detected only with difficulty, if at all, by those in an airplane seeking to drop bombs. But the light reflected from "green" foliage and that reflected from green paint are quite different owing to the carotin and xanthophyll in the foliage, so a light filter was invented in the laboratories of the Eastman Kodak Company which let the red and green light rays from the carotin and carotin-like substances pass through, but not the green rays reflected from chlorophyll. When the aviators viewed the landscape through such a filter, the natural vegetation appeared reddish and the "fake" vegeta-

tion of the camouflaged road stood out as a green line. As Dr. Ross Aiken Gortner has noted, this is a recent and striking

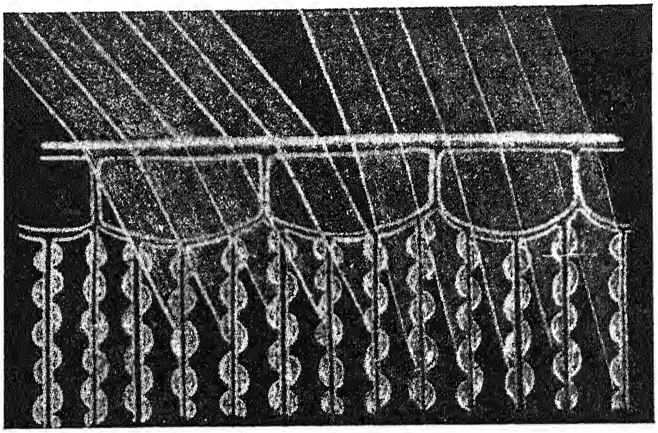


Fig. 44—DIAGRAM SHOWING HOW THE CHLOROPHYLL GRAINS IN THE PALISADE CELLS OF A LEAF ARE PARTLY ILLUMINATED BY LIGHT PASSING OBLIQUELY THROUGH THE EPIDERMAL CELLS

(*After Harold Wager*)

illustration of the fact that research in "pure" science, without reference to "practical" ends, may yield results of the greatest practical importance.

Autumn Colors of Leaves

It is hard to imagine a spring and summer landscape of any other color than green and the bluish effect of distance. Green is so related to our normal vision that it is restful as well as otherwise pleasing. If all foliage were red or yellow or almost any color but green, the season through, the effect on us would, no doubt, be quite distressing. But when the green color of the foliage gives place for a few weeks to glorious autumn hues, the effect gives us an esthetic pleasure which some have compared to that produced by beautiful music.

Yellow

The colors of autumn mean that the leaves have finished their work of manufacturing food by the energy of sunlight and are now senescent or dead. The leaves of pines and other "evergreens" remain green in winter because they remain alive for two or more years, but the leaves of deciduous trees (those that

shed their leaves each year) die and drop off each fall. One of the first steps in the death of a leaf is the fading of the chlorophyll. The two yellow pigments, carotin and xanthophyll, do not fade as readily as the chlorophyll and so they remain after the green has faded, and yellow is one of the commonest of autumn colors. By the same process the *green* stems of grain become *yellow* straw.

Red

The leaves of many plants ("Copper" Beeches, varieties of Maples—such as the Japanese and the Schwedler—Red Cabbage, Sumac, Barberry, and others) have a red pigment, *erythrophyll* (leaf-red), dissolved in the cell-sap. This color often masks the green, as may be shown by immersing such leaves in hot water. The hot water will dissolve out the red pigment, leaving the green. In the Schwedler Maple and some other trees the red color is deepest in spring and gradually fades as the days grow warmer, so that the leaves change from red or reddish to dark green in late spring or early summer. In still other plants, notably in the Sugar Maples and other trees whose leaves contain an abundance of sugar and *tannin,* the red pigment is formed as the chlorophyll fades. Bright light favors the formation of the red color, for the shaded parts of leaves remain green while the exposed portions turn red. This is why some leaves are yellow and others red; the former contain little or no sugar and tannin.

Brown

Brown color results from the oxidation (by enzymes) of tannin in the cell-walls, or of yellow substances in the cell-sap—a process similar to that which causes the surface of a freshly cut apple to turn brown. By different combinations of red, yellow, and brown various gold and bronze effects result.

White

In birches the green and yellow fade in rapid succession and no red is formed, so the leaves become white, one of the most unusual of autumn colors. The white color results from the reflection of light from the air in the leaf-tissue, just as the white

color of snow is due to the reflection of light from the air between the flakes.

Frost, or low temperatures near freezing, may hasten autumn colors by abruptly reducing the vitality of the leaf-cells, but frost is not necessary for the formation of fall colors. If a branch early in the season is broken or sufficiently injured by insects, so that it begins to die, the leaves will assume the colors normally characteristic of autumn.

The Fall of the Leaf

Toward the end of the season, in deciduous trees and shrubs, a layer of thin-walled, cork-like cells forms at or near the base of the leaf or of the leaflets, or, as in the Boston Ivy (*Parthenocissus*), at the base of the blade. This results in a layer of weak tissue, and also reduces or shuts off completely the movement of sap in and out of the leaf. This, of course, contributes

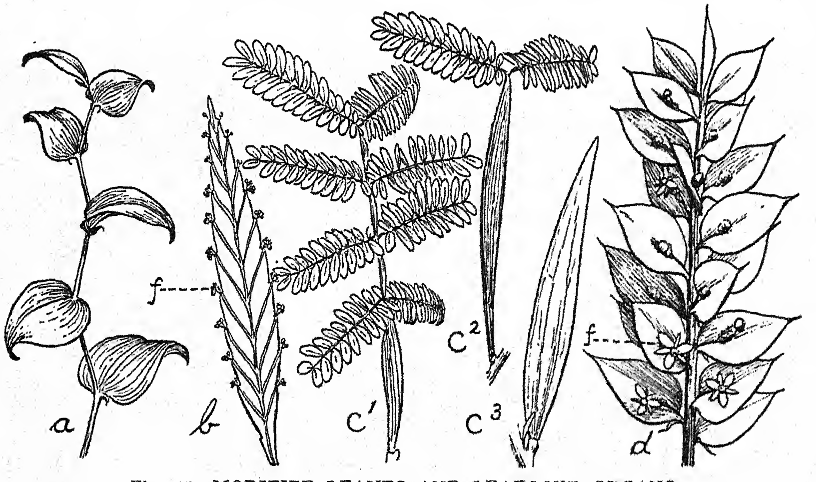


Fig. 45—MODIFIED LEAVES AND LEAF-LIKE ORGANS

a, Florists' "Smilax" (*Myrsiphyllum*), showing branches modified as leaves; *b*, Leaf-like stem of *Phyllanthus*; c^1, twice-compound leaf of an *Acacia*; c^2, another leaf on the same plant; c^3, a third leaf on the same plant, in which the compound leaf-blade did not develop, but the leaf-stalk resembles a simple leaf-blade; *d*, Butcher's Broom, the leaves reduced to small scales (as in "Smilax"), and the flower-bearing branches modified as leaves

to the death of the leaf and weakens its attachment so that it is readily blown away or falls easily by its own weight or when hit by birds or squirrels. Part of the weak, corky tissue remains on the branch where the leaf was attached, forming the surface of a *leaf-scar*, and preventing the loss of water by exudation and

evaporation after the leaf has fallen. In willows, poplars, and some other trees these *abscission* (cutting-off) *layers* form at the base of, or somewhere along, the branch itself, resulting in the *self-pruning* of a tree. During the fall one may find these shed branches, often with many fresh leaves still adhering, in considerable abundance on the ground under the trees. Ripe fruits are severed from the tree in a similar manner.

Knots and Knotholes

Self-pruning should not be confused with *natural pruning* which is caused by the excessive shading of the lower branches of trees in a forest so that photosynthesis almost or quite ceases in their leaves. By this the branches are undernourished; they finally die and fall or are broken off. The lower parts of branches become overgrown as the main trunk enlarges, and this is the cause of *knots* in timber sawed from such logs. The knots are cross-sectional pieces of these branches. If the branch was quite dead we have a dead knot, which readily falls out of the board, leaving a *knothole*.

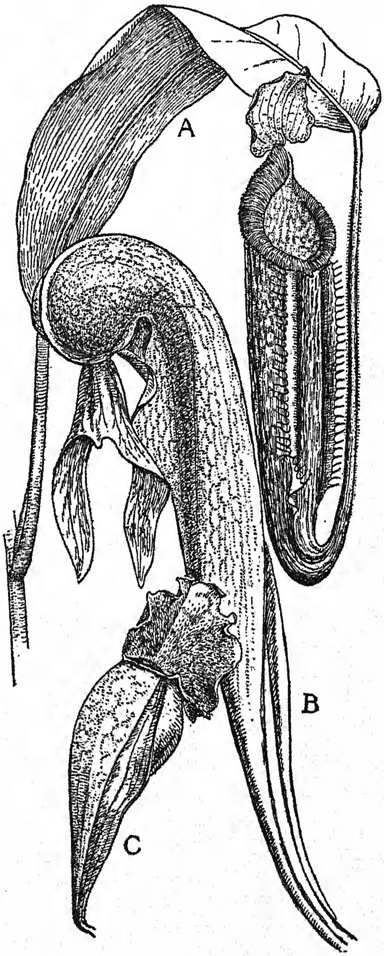


Fig. 46—LEAVES OF PITCHER-PLANTS

A, *Nepenthes*; B, *Darlingtonia*; C, *Sarracenia*

Forms of Leaves

We have now briefly discussed the essential facts about leaves—that they are green, thin, and flat, located at or near the tips of the branches, and oriented so as to secure the best amount of sunlight. But *foliage-leaves* appear under a great

variety of forms, with various kinds of margins, indentations, and even branching. Some modifications of leaves are illustrated in Figure 45, and are further described on pages 47 and 48.

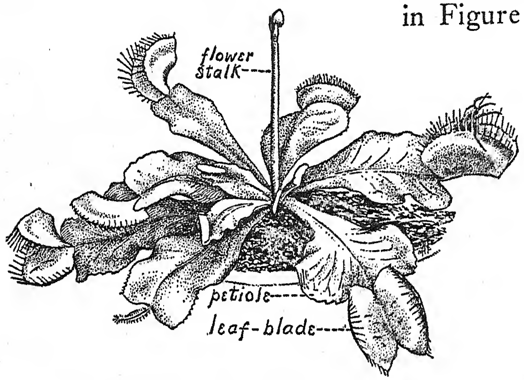


Fig. 47.—VENUS'S FLYTRAP (*Dionaca*)

But not all leaves are foliage leaves; structures which occur in the normal position and anatomical relation of leaves, so that the botanist says they are *homologous* to leaves, may appear as tendrils (as in the Pea), thorns (as in the Barberry), bud-scales (as in the Horse-chestnut and most other plants that have scaly buds), the petals of flowers, the petal-like *bracts* of Dogwood and Poinsettia "blossoms," and in other disguises.

Insect-Eating Plants

Leaves which catch insects are variously modified as pitchers (in the numerous Pitcher-plants), as traps (in the Venus's Fly-trap), or by having their surfaces covered with sticky, stalked glands (as in the various Sundews, as shown in Figure 48). Whatever the modification, these leaves of insectivorous plants all have glands which pour out a fluid capable of digesting the bodies of the captured insects. The digested material is then absorbed as food.

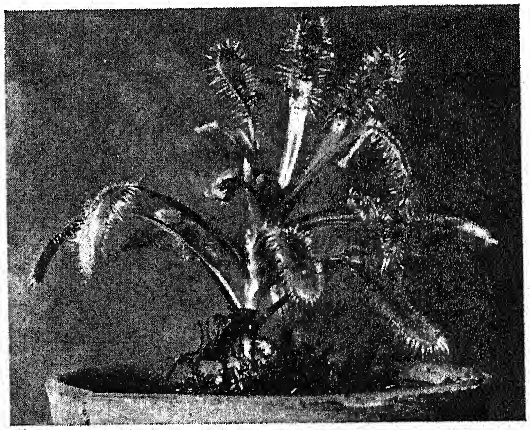


Fig. 48.—PLANT OF A SUNDEW (*Drosera*)
Showing leaves with fringe of glandular hairs, and numerous insects entrapped by the bending over of the sticky hairs

"Leaves" Which Are Not Leaves

One of the interesting, and often puzzling, problems of the botanist is to interpret the true (morphological) nature of structures that simulate what they are not. Examples of this

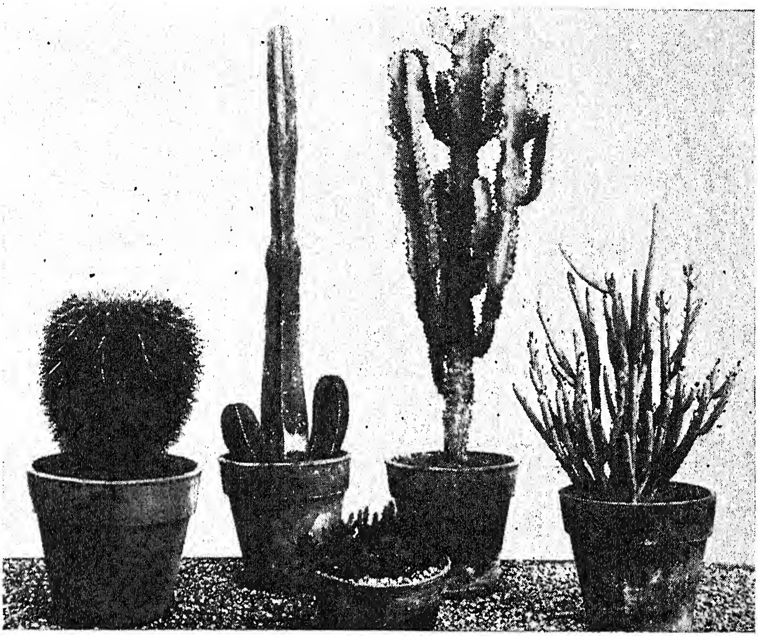


Fig. 49—SUCCULENT PLANTS

From left to right: Cactus (*Echinocereus*), cactus (*Pachycereus*), *Stapelia, Euphorbia, Kleinia*

are the organs on various plants that look like leaves but are really something else. This is illustrated by the "Smilax" of the florists, which is not botanically a smilax (*i.e.*, the genus *Smilax*), but a species of the genus *Myrsiphyllum*. In that plant the leaf-like organs are flattened branches that function as leaves. The numerous fine branches of the mature edible Asparagus, often taken for leaves, are stems, the leaves being reduced to very inconspicuous scales, like those on the succulent young stems we eat, only smaller. They are not *foliage* leaves. The leaf-like structures of the tropical *Phyllanthus* (Flowers-on-the-leaves) are really branches. The fact that these organs bear flowers on their margins led to the name, which is really a mis-

nomer. In several Acacias the leaf-blade fails to develop on the older leaves, the leaf-stalk becoming thin, flat, and green, and performing all the functions of a leaf. Branches of the European Butcher's Broom appear to be leaves, but their stem-like nature is revealed by the fact that they grow in the axils of leaves (as do all branches), and also bear flowers. (See Figure 45.)

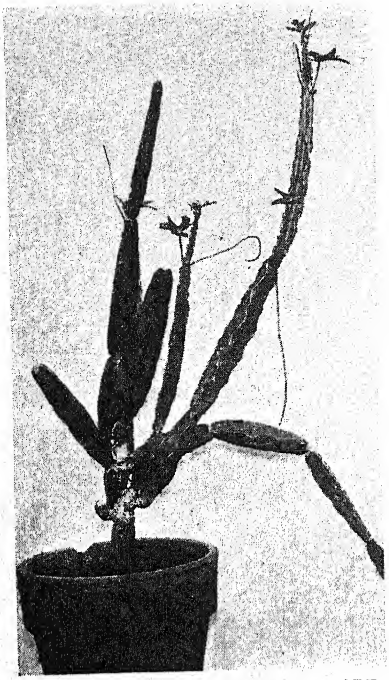


Fig. 50—EDIBLE-STEMMED GRAPE (*Vitis quadrangularis*)

Plants Without Leaves

Many plants have no leaves except the seed-leaves of the embryo. This is true of most cacti, which depend wholly upon the chlorophyll in their leafless stems for photosynthesis. A similar peculiarity, which may be interpreted as an adaptation to desert conditions, is seen in many *Euphorbias* (often mistaken for cacti) and *Kleinias*. The Edible-stemmed Grape (*Vitis quadrangularis*), of North Africa, puts forth small foliage leaves on new growth of stems, but they are short lived, and a mature plant, much of the time, appears quite destitute of leaves.

Leaves Without Plants

Of course, strictly speaking, "leaves without plants" is an impossible conception. The idea is suggested, however, by plants of such simple structure as the common duckweeds, which are various species of *Lemna* (related to the Calla Lily and the Jack-in-the-Pulpit). They include some of the smallest and simplest flowering plants, and the German botanist, Karl Goebel, interprets them as *free-living leaves.* If that is correct, they bear flowers on their leaves—a very unusual if not unique circumstance.

Roots as Leaves

One of the strangest usurpations of the function and appearance of leaves is found in a genus of orchid, *Taeniophyllum,* native in tropical Asia and Oceanica. This plant grows on the surfaces of other plants in tropical rain forests.* Even the seed-leaves of the embryo are wanting, and the foliage-leaves, where present at all, are reduced to non-green scales. The strap-shaped green roots perform all the life-functions of green leaves.

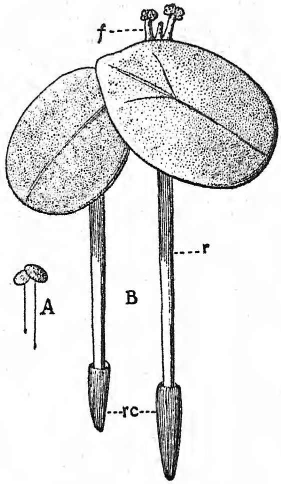


Fig. 51—DUCKWEED

A, natural size; B, enlarged
r, root; *rc,* root-cap; *f,* flowers

Getting a Drink

Nothing is known that can live, except for a limited period, without water from some source. A man can live without water for a few days only. Such insects as moths and carpet bugs, which subsist on air-dry food, such as rugs and carpets, apparently live their entire lives without taking in water from their environment, but, as Prof. S. M. Babcock, late of the University of Wisconsin, first demonstrated, they compensate for this by reabsorbing the water formed by chemical processes within their own bodies. It has been shown that some bacteria can live, but for a brief period only, when completely desiccated. Seeds are perhaps the best illustration of the ability to maintain life for a period (but only for a period) without a supply of water from

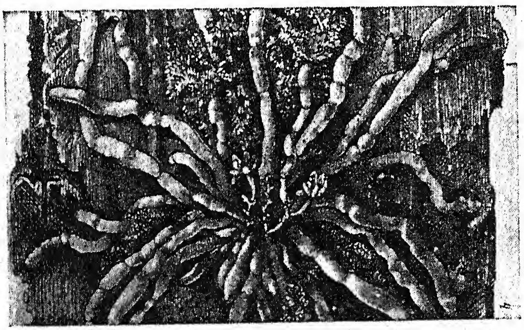


Fig. 52.—ROOTS SERVING AS LEAVES

In *Taeniophyllum.* (*After Wiesner*)

* A rain forest is a tropical woodland in which the annual rainfall exceeds forty inches.

without. An extreme case, so far as we know, is the seeds of the East Indian Lotus (*Nelumbo nucifera*), specimens of which at least a hundred years old and possibly two to three hundred years were found in Manchuria in 1923 by the Japanese botanist, Dr. Ichiro Ohga, and were reported to be capable of germinating. All living seeds contain some water. The "Resurrection Plant" (a species of Little Club Moss, *Selaginella*) illustrates a plant-body capable of resuming its life-functions after remaining air-dry for months. The Grama grass of the semi-arid regions of the western United States may also, after being "dried out" during drought, resume its activity with the first shower.

How Much of a Plant Is Water?

By weighing plants or plant parts before and after thoroughly desiccating them in a drying oven, it has been found that a large percentage of their weight is water. Three-fourths (75 percent) of the weight of a potato tuber is water; of a clover plant 78 percent; of fresh meadow grass 80 percent. Of aquatic plants the percentage of weight due to water may reach 95 percent or more. The percentage of water is low in seeds; for example, bean seeds 15 percent, oat grains 14.3 percent. All plants are, in a sense, "aquatic" plants, the expression "dry land" being, of course, only relative.

The Meaning of Roots

Everyone knows that if the leafy stem of a plant is cut off it dries up. This shows that water is not taken in but given off by stems and leaves. Even though the air is very humid, little if any moisture is absorbed by the branches and leaves of our common plants. This is the function of roots. They serve both to fasten the plant in the soil and to absorb the soil moisture, which consists of water containing various substances in solution which are taken in with the water.

How the Water Gets In

In the case of most land plants the soil-solution is absorbed by means of special organs, the *root-hairs,* which occur only on a short region just back of the tips of young roots. The molecules and ions of the weak solutions inside the root-hairs are

pushing against the inside of the cell-walls, and the more numerous molecules and ions of the stronger soil-solutions are pushing against the outside of the walls; the result is that matter passes both in and out, but more rapidly to the inside. The process is called *osmosis,* from the Greek word *osmos,* which means pushing. Thus the plant is kept supplied. No solid substance can enter a plant except in solution.

That "dry land" is only a relative term will be realized when we note that there is more water in the soil of the world than in all the inland lakes and seas and the atmosphere (as water vapor) taken together. If the amount of water in the ocean is taken as 1.0, the amount in the soil is 0.005, but in the lakes and inland seas only 0.00009, and in the atmosphere (as water vapor) 0.000009.

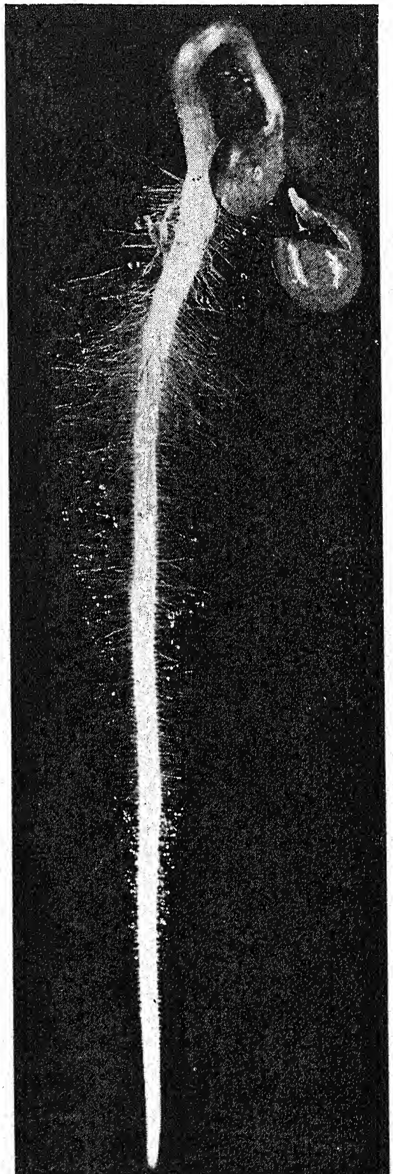


Fig. 53—ROOT-HAIRS ON SEEDLING OF WHITE MUSTARD

Enlarged four times

Note their absence from the region of growth just back of the root-tip

How the Water Gets Out

Obviously, if water is continually entering a plant whose tissues are already saturated, water must be continually leaving, otherwise the plant would swell up and (possibly) burst. The water passes off through the tiny openings (*stomata*) in the surfaces of leaves and young stems, but chiefly through the

Fig. 54—LEAF-EPIDERMIS OF INDIAN CORN

Photographed through the compound microscope, showing stomata. About one-half a square millimeter of leaf surface is represented

(*After Kiesselbach*)

leaves. The amount thus given off may reach astounding figures. Thus a Sunflower plant having thirty-two square feet of leaf surface (measuring both upper and lower surfaces) has been found to lose water at the rate of one and a half pints in each twelve hours of daylight. Stephen Hales, a pioneer English plant student, reported that an average crop of Cabbages loses four tons of water (over 1000 gallons) per acre in one day. An Elm tree having about 7,000,000 leaves was found to have about five acres of leaf surface (both sides of the leaf included), and gave off to the air $7\frac{3}{4}$ tons of water in twelve hours of clear, dry weather. Most of this water passes out of the leaves through the stomata and then evaporates into the air. The process is called *transpiration,* since the vapor passes *through* the stomata.

Where Dew Comes From

Much of the water found in the morning on "wet grass," and called *dew,* does not "fall" (as we commonly say), but is water that has passed out of the grass leaves as water-vapor, and condensed in drops during the night when the air was too humid and cool for the vapor to pass into the air as fast at it came out of the leaf.

How the Water Gets Up

The soil-water (by which we mean water plus the substances dissolved in it) entering the root-hairs by osmosis, passes along the root from cell to cell by osmosis and also by capillarity along the cell-walls (soaking the cell-walls), just as a blotter takes up

ink or as melted wax passes up the wick of a candle. The blotter and the wick are both made of cell-walls. The passage of the water is facilitated by special tubes and ducts in the woody part of the roots and stems (main stem, branches, and leaf-stalks). The "pulling" force results from the continual loss of water from the leaves in a manner too complex to be discussed here. Other forces are doubtless involved. The whole process, known as "the ascent of sap" is not perfectly understood, but the pulling force resulting from transpiration is, perhaps, the main factor.

How the Elaborated Food Is Distributed

While the soil-solution is passing up from roots to leaves *through the wood* the solution of food (sugars, proteins, etc.) elaborated in the leaves is passing *down through the inner layers of the bark,* where it nourishes all the active cells, including the new buds that are forming at the tips of branches and along their sides at or near the *leaf-axis* (the upper angle made by the leaf-stalk and the branch).

Nutrition an Electrical Phenomenon

Since the particles in solution in the soil-water, the elaborated sap, and the cell-sap all bear charges of positive and negative electricity, it will be seen that plant nutrition is, in reality, an electrical phenomenon. Such is the modern view of physiologists. The particles at the surface of the protoplasm of a cell have a negative electric charge; those within a positive charge.

The Struggle with Drought

The fact that plants are continuously losing water by transpiration makes it a very serious matter if the supply is not constantly adequate. When it is not, the plant experiences *drought.* Some plants are better adapted than others to withstand drought conditions. This is accomplished in many ways, including the following:

Leaf Modification. The leaves may have a waxy coating or "bloom" (Pineapple and Cabbage), or a thick surface-layer of cuticle (Carnation), or be covered with hairs on the underside where most of the stomata are (Labrador Tea), or on both

sides (Mullein), or have their edges rolled toward the under side to form a humid chamber (Rhododendron in winter), or be thick and succulent (Live-forever, *Sedum,* Century Plant, Aloe, etc.), or have the leaf-blade reduced so that there is little left but the veins (New Zealand Blackberry), or have no stomata on one side (Lizard's Tail and Lilac).

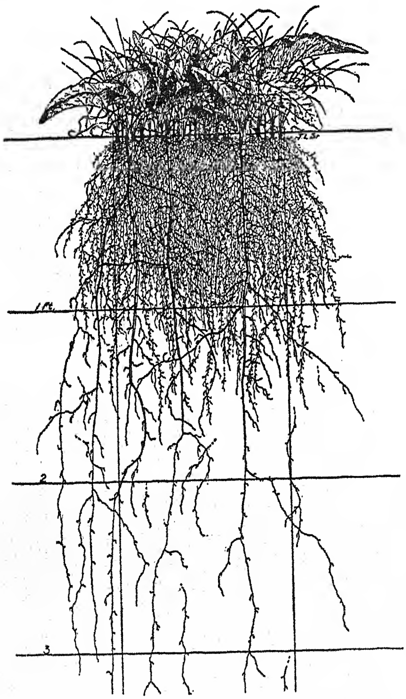


Fig. 55—ROOTS OF A BURDOCK (THE BROAD LEAVED PLANT) IN COMPETITION WITH THOSE OF A BEARD GRASS

Although the Burdock has deeper roots and better light relations, the very dense root-system of the grass enables it to crowd out the Burdock

(After Weaver)

A Layer of Cork. This is illustrated by all woody plants (trees and shrubs), which have a layer of cork-tissue completely surrounding the wood of the stem system and often of the roots. This prevents the evaporation of the water solutions as they pass up and down, to and from the leaves. The Cork Oak is a conspicuous example of this, but all woody plants have it more or less. A deciduous tree, after the fall of its leaves in autumn, is as effectively "corked up" as is a bottle with the "cork" in. Whereas a Maple tree thirty-five feet high might lose a barrel of water by transpiration and evaporation on a hot dry day in summer, H. L. Knisely found that a Soft Maple of that size lost only six to seven pints when dormant in winter.

Getting on without Leaves, as is the case with the edible stemmed grape of North Africa, Euphorbias, Cacti, and others. The Cacti may be taken as typical desert plants, for not only do they lack foliage-leaves, but they have a very succulent stem, with a thick skin coated with bloom. Moreover, the stem is armed with spines which reduce the chances of its being eaten by animals in a location where plants for animal food are scarce.

Extensive Root System. The root system is often very extensive, being greatly branched and extending for many feet both downward (twenty feet deep for a Rose) and sideways (over twenty-five feet from the stem for a Bush Morning-glory), so

Fig. 56—ROOT OF A PEACH TREE
Nineteen feet long
(*After H. P. Gould*)

as to be able to take advantage of every trace of water within a wide radius. Dr. John Ernest Weaver, of the University of Nebraska, traced the roots of a *Yucca glauca* to a distance of thirty-two feet in all directions at a depth of six to eighteen inches. Dr. Friedrick Nobbe, a plant physiologist of Germany, found the total length of all roots of a one-year-old wheat plant to measure 1500 to 1800 feet, and Prof. Julius von Sachs, a German botanist and the founder of the modern science of experimental plant physiology, reported a large gourd as having a root system twenty-five kilometers, or over fifteen miles, long. Even with the cabbage previously mentioned, Hales found that the root system was 470 feet long. The root system of an oat plant was found to be 450 feet long; that of a large tree might exceed a mile in length. The root-hairs on such systems of roots would present a surface of many square feet through which water could be taken in.

The prevalent notion that the feeding roots of trees extend out at least as far as the tips of the branches is correct. Dr. Weaver, who has made the most extensive studies of root systems ever made, says, in a letter to the author, that the roots of shade trees, fruit trees, and forest trees, so far as his own observations go, "spread much more widely than the tops—in the bur oak, for example, at least in Nebraska, two or three times as far as the branches."

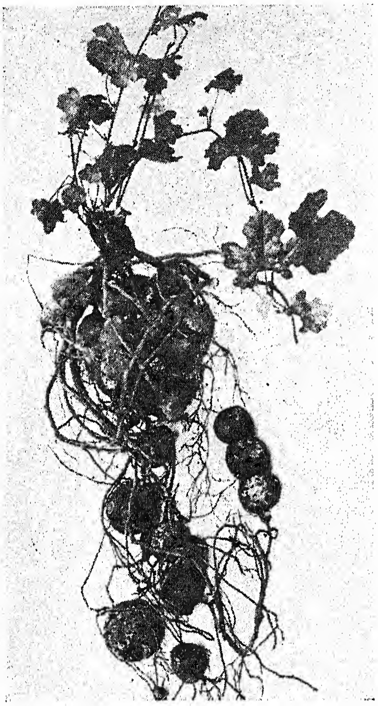


Fig. 57—ROOTS OF AN AFRICAN GRAPE (*Vitis capensis*)
With globular enlargements for water storage

Storing Water

Nearly every organ is utilized by one plant or another for the storage of water on which the plant may draw in time of drought: in Cacti, Euphorbias, Kleinias, Ibervilleas in the stem; in Aloes, Century Plants (*Agave*), Live-forevers (*Sempervivum*), Stonecrops (*Sedum*) in the leaves; South African Grape (*Vitis capensis*), Fern (*Nephrolepis tuberosa*), Bush Morning-glory (*Ipomoea leptophylla*) in the roots. Some Eucalyptus trees store so much water in their roots that native Australians utilize them for drinking water in periods of drought. Indians of the North American desert have utilized some of the large cacti as a source of drinking water. Certain desert plants have enough water stored in their tissues to last several years—in the Mexican *Ibervillea* at least six years.

Plants Which Drink Out of Their Own Leaves

In the rain forests of the tropical Old World there is a relative of the Milkweed which is an *epiphyte,* that is, it grows on other plants, but derives no nourishment from them. This

plant, *Dischidia,* has its leaves modified as "pitchers" about four inches long, containing a sort of soil formed of dust and other débris, and water caught by the pitchers when it rains. Roots of this plant grow from the stem down into the pitchers and absorb the water and the food-elements dissolved in it, so that the plant drinks and feeds from its own leaves.

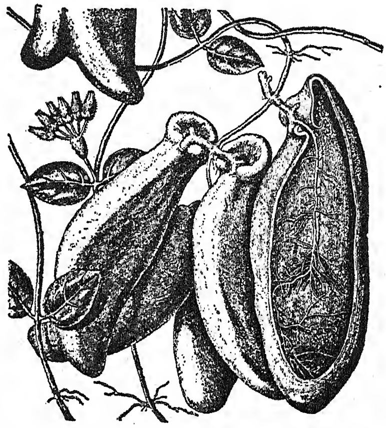


Fig. 58 — LEAVES OF *DISCHIDIA RAFFLESIANA* (A VINE RELATED TO THE MILKWEED), MODIFIED FOR WATER STORAGE

(*After Palladin*)

Every one has seen drops of water on leaves of Waterlilies, globular in shape and rolling around like water on a hot stove. This means that the water cannot wet the leaf-surface owing to the nature of the cuticle. But the surface of some leaves is slightly "wetable" by water, and in such cases the leaf may absorb more or less. In the common Teasel, the bases of the opposite leaves form a cup around the stem. Water that collects in this cup may be absorbed, but in the Teasel and most other land plants growing in the soil such a source of water is neither essential nor important.

No leaves are more curiously modified than those of the various Pitcher-plants — *Sarracenia, Darlingtonia, Nepenthes,* etc. (See page 45.) The leaf-stalk is in the form of a tube or cornucopia, with a lid at the top which is the leaf-blade. At the margin of the pitchers are glands which secrete nectar. This attracts insects, some of which become finally trapped in the pitcher by numerous hairs on the inner surface which point downward and make it quite impossible for the trapped insect to crawl up to the rim. A portion of the inner surface is so slippery as to further impede the insects, which finally fall into the liquid at the bottom. This liquid secreted, in part, by cells on the inner surface of the pitcher, contains a juice which can digest insects or small pieces of lean meat. Thereafter the solution of digested protein is absorbed by certain cells on the inner surface. The plant, however, is not dependent on either the water or the dis-

solved food obtained in this way. There are numerous kinds of land and aquatic plants whose leaves are modified to capture insects, and digest and absorb them (see also page 46).

Plants Without Roots

We have seen that there are plants without leaves, and "leaves without plants"; there are also flowering plants that have no roots. Perhaps one of the most familiar of these is the so-called Florida Moss (*Tillandsia*), which is not a moss, but a member of the Pineapple family. The plant body is a thread-like, branched stem, which acquires a length of several feet, and possesses many small grass-like leaves. The plant grows in great abundance in southern United States, hanging from trees, and even growing luxuriantly on telephone wires. Although it bears flowers it is rarely propagated by seed, but by portions of the stem which become broken off and are blown about by the wind or carried by birds. This plant obtains all its water by means of special shield-shaped hairs which thickly cover its surface and hold by capillary attraction every drop of water that falls or condenses on the surface. The water is then absorbed by surface cells.

The Philosophy of Weeds

Just as wild animals compete with each other for food, so also do roots compete for water in the soil. Plants having shallow-growing roots can live close to deeply rooted plants better than they can to other shallow-rooted plants. Thus the farmer can grow pumpkins (shallow-rooted) with corn (deep-rooted). Herein lies the philosophy of weeds. As a Canadian writer has well said, "A big weed takes a barrel of water out of the soil. A crop of wheat takes 900 tons of water per acre; *so does a crop of weeds.*" So great a menace are weeds that the Province of Manitoba, Canada, has enacted a law against their spread.

The Man with the Hoe

Water is such a fundamental and indispensable need that much of the work of the farmer and gardener consists in preventing its escape from the soil except by passing through the

crop plants. This explains, in part, the practice of hoeing. In the first place it keeps down the competing weeds, and in the second place it keeps the surface of the soil pulverized so that it acts as a mulch (*e.g.*, like a surface layer of straw), preventing the evaporation of water directly from the soil and thus conserving it for the crop plants.

For years farmers have prepared the ground for winter wheat with a view to conserving the soil moisture, plowing early in summer (by July 15) to keep down thirsty weeds, and plowing seven inches deep to provide a thick mulch. It is now recognized that early plowing also prevents weeds from removing nitrates from the soil before the grain is sowed, nitrates being essential for a good crop of grain.

Tank Plants

In the rain forests of Brazil and elsewhere in tropical America, there are numerous kinds of *Bromeliads*, relatives of the Pineapple, which live as epiphytes (see page 56) on the

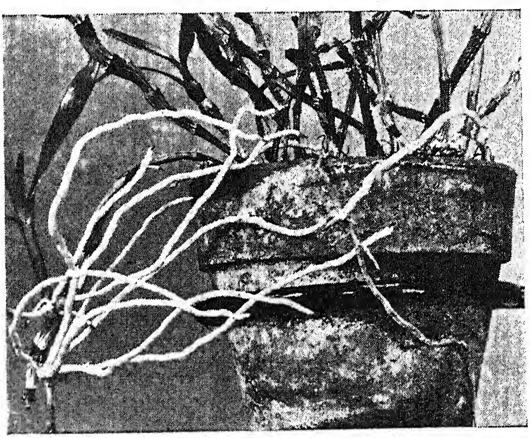


Fig. 59—ORCHID PLANT

With white aerial roots covered with spongy *velamen*, which absorbs moisture from the air

branches of trees. Their leaves have no leaf-stalk and are stiff and horny, having spiny margins; the surface is covered with thick cuticle and a waxy bloom, so that they lose very little water by transpiration. These leaves form a compact rosette and their bases are expanded like spoons so as to form receptacles

that hold water. For this reason the plants have been called, by Schimper, *Tank-epiphytes.* A large plant may hold as much as a quart of water which is absorbed (together with dissolved nutrients that may have fallen into it) by scale-like hairs, situated on the inner surface of the leaf-bases. The roots absorb little if any water or nutrients, and serve chiefly to hold the plant to its support.

Roots in the Air

Many Orchids which grow as epiphytes depend for their water supply largely or wholly on their aerial roots. These roots have an outer tissue called *velamen,* of a spongy nature, filled with air when dry and therefore white (see page 43). Whenever a drop of water falls or condenses on the surface it is quickly absorbed. Often these roots possess chlorophyll and so perform a double nutritive function.

Plants Which Live on Salt

As is well known, not all plants grow in soil. We are familiar with floating aquatic plants, but some plants live on moist salt (*e.g.*, the Algae—*Chlamydomonas, Dunaliella,* etc.); others (certain bacteria) live in hot springs, still others on snow and ice (bacteria, and the "Red Snow" referred to on page 14). Plants which can live in concentrated salt solutions have in their cells an excessive amount of colloids which absorb and firmly hold large amounts of water, so that osmosis cannot withdraw from them sufficient water to cause their death—as would occur in organisms without such colloids.

CHAPTER VII

LIVING TOGETHER

Plant Societies

Certain plants (*e.g.,* Mountain Ash, Broom-rape, and Baneberry) are rarely found several or many together, but one here, another there. Most kinds of plants, however, grow in larger or smaller groups, forming *plant societies,* like pines, hemlocks, grasses, daisies, bracken ferns, and others.

This grouping may have no recognized advantage, being merely an expression of the habit of growth of the plant. Such is the case with the very "sociable" bracken fern, all the "plants" of which in a given field or hillside may in reality be only one plant—all the individual groups of leaves coming from the same very long and much branched underground stem. In other cases the social habit may be very essential, as when plants have their male (*staminate*) and female (*pistillate*) flowers on separate plants, as in Hop, Ailanthus, Dates, Smyrna Fig, and Willow. In that case it is an advantage, of course, that staminate and pistillate plants grow near together so that pollen may more surely reach the pistillate from the staminate plants.

Plants Which Live on Other Plants

The problem of food and drink has been solved by many plants by acquiring the habit of living together as partners. This method of living is called *symbiosis,* from two Greek words meaning "living together." The entire group known as *Lichens* is composed of plants that consist of a green alga and a fungus living in intimate partnership. The alga depends upon the fungus for its water and, in turn, by photosynthesis (see page 36) provides its fungus partner with its necessary carbohydrates. Various kinds of lichens grow closely appressed to boulders and other rocks, often appearing merely as patches of discoloration of the stone. They are the primitive soil-formers, dissolving

their mineral nourishment from the solid rock, and affording a moist surface to which dust and plant and animal débris adhere, until gradually there accumulates sufficient soil for mosses, then for ferns and higher plants. The type of symbiosis where both plants profit by the partnership is *mutualism.*

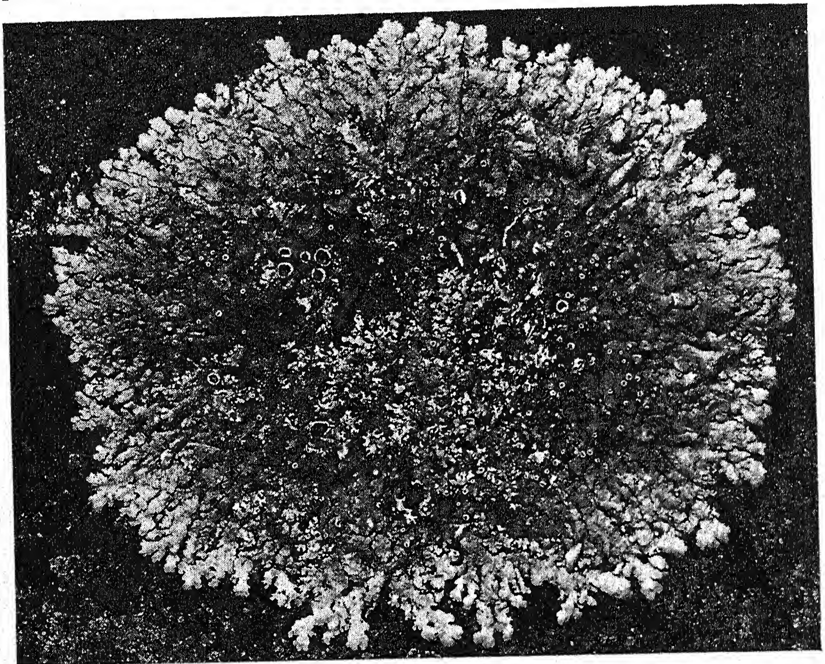


Fig. 60—PLANT OF A LICHEN (*Physcia stellaris*) GROWING ON THE SURFACE OF A ROCK

A striking case of mutualism is found in the partnership between certain bacteria and plants of the Clover Family (Peas, Beans, Clovers, Locust trees, Lupines, Peanuts, Wisteria, and others). All plants must have nitrogen and the chief ultimate source of nitrogen is the atmosphere. Green plants have little if any ability to utilize directly the atmospheric nitrogen, but certain bacteria are able to do this. Some of these bacteria seem not to be able to live an independent existence, but live in the roots of members of the Pea Family supplying the latter (as well as other plants) with nitrogen (in the form of nitrates) in return for a place to live and sugar for food. These bacteria stimulate the roots to form small nodules or tubercles in which they live.

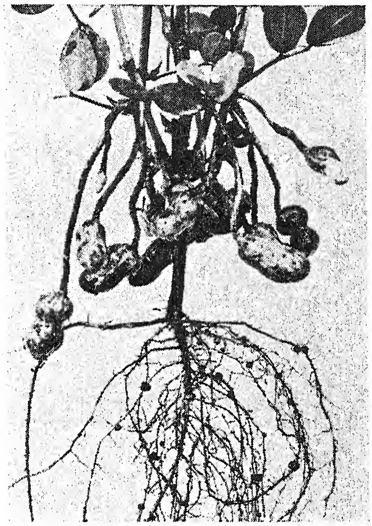


Fig. 61—PORTION OF A PEANUT PLANT

Showing the peanuts formed underground, and the root-nodules caused by nitrate-forming organisms

Many trees (Orange, Maple, Hickory, Oak, Birch, Beech, Larch, and others) have few or no root-hairs, but depend upon the filaments of various fungi for absorbing the soil-solution. The fungi may live on the surface of the roots (Hickory) or in their tissues (Red Maple). Such fungi are called *mycorrhizas,* which means "root-fungi." By some authors the term is used in a more strict etymological sense (*fungus-root*) to designate the root itself.

Parasites

In some cases of symbiosis only the plant which lives on the other plant benefits from the association. It is then called a *parasite,* from two Greek words meaning "to get food alongside of another," and at the expense of the other. The parasitism may be almost or quite complete, as in the case of Dodder, or incomplete as in the case of Mistletoe. Dodder seedlings have roots and live in the soil like other plants, but they soon come in contact with a *host-plant,* twine around it (being a vine) and send "sucking" organs into the tissues of the host. These absorb all the nourishment the Dodder needs, the end of the root dies off, and the Dodder becomes wholly dependent on the host plant, flowering and fruiting. In connection with acquiring the parasitic habit the Dodder has lost all of its chlorophyll because it became parasitic, or it became parasitic because it lost its chlorophyll—who can say which?

The Mistletoe retains part of its chlorophyll, but apparently not enough for an independent existence.

All disease-causing fungi are parasites, living on other plants or on animals.

Saprophytes

"There was an old belief that in the embers
Of all things their primordial form exists,
And cunning alchemists
Could re-create the rose with all its members
From its own ashes. . . ."

Thus sang Longfellow in *Palingenesis*. There is an element of truth in this old "legend," for all plants, directly or indirectly, draw on the decayed remains of former plants (and animals) for part of their nourishment; in other words, on humus, the most important constituent of "top-soil" or *loam*, which is absolutely essential to agriculture. Thus, the organs of plants (their "members" as the poet calls them) are formed in part from material produced by the decay of previously existing plants. In some cases, as when lawns, meadows, or forests are burned over, the succeeding vegetation is nourished, literally, by the embers or ashes of the former plants.

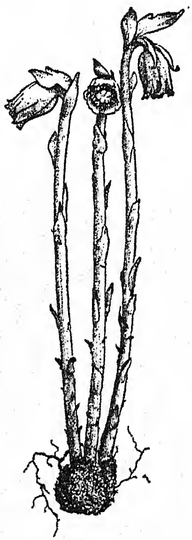


Fig. 62—INDIAN PIPES
They grow on decaying vegetable matter

The most fundamental human industry is, therefore, dependent on the products of decay, produced by enzymes secreted by plants. As we have noted before, decay is caused by fungi and bacteria, and plants that live on the decaying or decayed remains of other plants or of animals are called *saprophytes* (decay-plants). Some saprophytes are flowering plants—for example, the Ghost-plant or Indian Pipe, the Coral-root, and others. Such plants, in the words of Tennyson, "rise on stepping-stones of their dead selves to better things."

CHAPTER VIII

GETTING A BREATH

PLANTS, like everything alive, not only feed, drink, grow, and reproduce, but they can do none of these things unless they respire. Respiration is the process by which energy is supplied to living cells by the *oxidation* of some of their substance, which is thereby consumed. The process is somewhat comparable to that by which energy is obtained by the oxidation of coal in a furnace, only in a furnace the process is so vigorous that both heat and light result. This is *combustion*. In plants and animals no light but only heat results—that is, oxidation takes place but not combustion. In our own bodies the cells of our fingers or hearts (in fact all living cells) respire. The oxygen is taken in by our lungs. This is *breathing*. As a rule, respiration in plants is the same as in animals, oxygen being consumed, carbon dioxide given off, and the body temperature maintained or raised. Thus leaves are not, as is often said, "the lungs of plants" any more than are the roots or stems. Leaves might more properly be called "the stomachs of plants."

Respiring Without Air

Certain plants obtain their oxygen for respiration, not from the outer air, but from chemical processes that give off oxygen within their own tissues. Pea seeds, for example, are able to respire that way (*anaërobically*) though ordinarily they do not do so. Some organisms respire in that manner normally (*e.g.,* those that cause *sinus* infection in human beings). Other bacteria obtain their energy by oxidizing sulphur (producing sulphureted hydrogen, as in decaying eggs), or iron (thus promoting the rusting of iron). In 1930 bacteria were described which "breathe" hydrogen instead of oxygen, detaching it from the molecules of certain complex organic compounds and thus releasing energy for their own needs.

Special Organs for Breathing

As a rule, plants have no special organs, or lungs for breathing. The oxygen from the air enters the tissues of plants only by diffusion, just as, for example, the scent of a flower (which is a gas given off by a volatile liquid) may fill an entire room by the same process.

But the Swamp Cypress of our southern States, growing, as it does, in swamps, appears not to be able to acquire from the poorly aerated soil enough oxygen for its submerged roots, as do trees that grow on the "dry" land. It therefore sends up into the air peculiar looking organs called Cypress "knees," which seem to have no other object than *aeration*. Numerous palms, the Screwpine, the Sugar Cane, and other plants also have special organs called *pneumathodes*, which appear to be chiefly for the aeration of the plants.

Respiration Versus Photosynthesis

It is one of the most widespread erroneous impressions about plants that their respiration is the reverse of that of animals. This error results from confusing the process of photosynthesis, which releases oxygen in sunlight, with respiration, which consumes oxygen in both light and darkness. In sunlight both processes take place in green tissues at the same time, and some of the oxygen released by photosynthesis is no doubt at once consumed by respiration, while some of the carbon dioxide given off by the respiration of the green tissues may, *in sunlight*, be utilized for photosynthesis.

If Alice (in Wonderland), when she grew smaller and smaller, could have slipped through one of the tiny stomata of a leaf into the air space between the cells, and if oxygen were red, carbon dioxide blue, and water vapor yellow, Alice would have seen, during the daytime, tiny streams of red and blue gases passing by diffusion *in and out* of the stoma *at the same time*, and yellow water vapor passing out. At night the blue carbon dioxide would be going in only one direction—out. But Alice would have been very uncomfortable, for she would have been standing on a wet, slippery surface (a cell-wall) in an atmosphere at about 100 percent humidity.

CHAPTER IX

WHAT IS A FLOWER?

ALL the activities described in the last three chapters are concerned in maintaining the life of the individual plant, but in describing the various kinds of plants we included activities for maintaining the life of the race to which the plants belong. In the flowering plants these activities for the race are the function of the flower.

Every schoolboy (as Macaulay said) knows that flowers have *petals* (from a Greek word meaning leaf), commonly brightly colored. All the petals taken together constitute the corolla (little crown). Outside the petals is another circle of parts called *sepals*, from a Latin word meaning "separate from (or different from) the petals." The sepals together constitute the *calyx* (cover). At the center of the flower are one or more *pistils*, so called because shaped like the apothecary's pestle. The lower portion of the pistil is called the *ovary* because it contains one or more *ovules*, each of which contains an *egg-cell*. A portion of the upper end of the pistil is specially modified, being glandular or sticky or covered with very fine hairs. This is the *stigma* (mark); it is one of the very few parts of the plant which have no epidermis. Often the stigma is at the end of a prolongation of the ovary called the *style* (from a Latin word, *stylus*, meaning little pillar). Between the corolla and the pistil (or pistils) are several *stamens*, each usually comprising a slender stalk, the *filament*, at the end of which are one or more *spore-cases*, here called the *anthers* (from a Greek word meaning

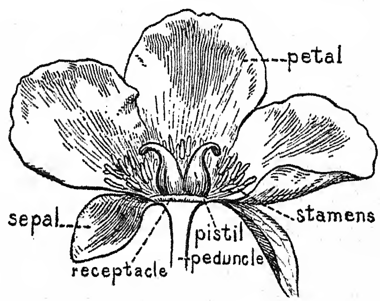


Fig. 63—THE PARTS OF A FLOWER
Redrawn from Coulter, Barnes, and Cowles

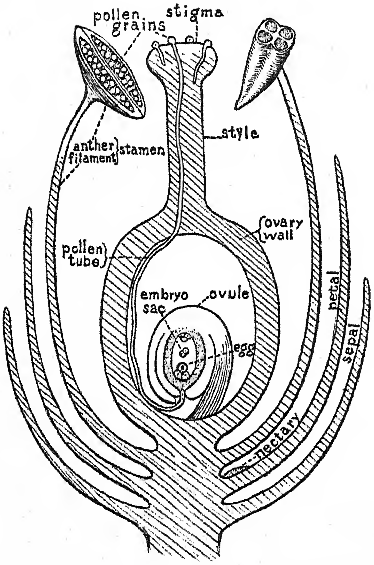


Fig. 64—DIAGRAM OF THE PARTS OF A FLOWER SHOWN IN LONGITUDINAL SECTION

flower). The mature spores are collectively called *pollen* (Latin, fine flour). Each pollen-grain may contain two *sperms*. The flower is really a modified branch, the parts just described representing modified leaves borne on the *flower-stalk*.

What Flowers Are For

It is the function of flowers to make seeds. The making of a seed involves the following processes:

Pollen must be carried from the anther to the stigma. This is *pollination*. On the stigma the pollen *germinates*, sending out a *pollen-tube* that passes down through the style to the ovary, and to an opening or *micropyle* (little gateway) in one of the ovules. In some plants the sperms are formed in the pollen-tube after the germination of the pollen-grain. After the end of the pollen-tube enters the micropyle it opens (possibly being digested away), and the sperms pass out. They do not have the power of locomotion as in Ferns or Cycads. Next, a sperm-nucleus enters an egg-cell and fuses with the egg-nucleus, thus accomplishing fertilization. The fertilized egg-cell then divides into two cells, the two into four, and so on until an embryo plant results. Meantime the parts outside the fertilized egg-cell are growing and maturing. By the time the embryo is complete (*e.g.*, in the bean or maple) the ovule has become a seed. *Seeds are ripened ovules.*

What Is Fruit

While the ovules are becoming seeds the ovary is growing and maturing. A *ripened ovary* is, botanically, *a fruit*. The ripened ovary itself may be supplemented by the growth of adjacent parts—the end of the flower-stalk as in pears, the calyx as in apples, the receptacle (tip of flower-stalk) as in straw-

berries. Such complex structures are also called "fruit" (in a more popular sense) by gardeners, farmers, and consumers.

Who Discovered the Secret of Flowers?

We should not conclude our discussion of flowers without acknowledging our indebtedness to the careful students who first explained the botanical meaning of flowers and interpreted correctly the functions of their various parts. For this work we are largely indebted to the German botanist, Rudolf Jakob Camerarius (1665-1721) who, about 1694, was the first to demonstrate sexuality in plants and the necessity of pollination for the formation of seeds; and to the Italian botanist, Giovanni Battista Amici (1786-1863), who, in 1839, was the first to prove that the embryo develops in the ovule as a result of fertilization. Formerly the German botanist, Matthias Jakob Schleiden (1804-1881), had taught that the embryo was first formed at the end of the pollen-tube and merely deposited in the ovule for further development. He even published illustrations showing the various steps in such a process. The error was largely due to the imperfections of the microscopes of that day, but credit is, however, due to Amici for really being the better observer.

The ability to observe and describe accurately is a high art. Few possess it. It is characteristic of all great scientists and absolutely indispensable for the development and advancement of science.

Civilization and Seeds

In the opening paragraphs of this book we noted the dependence of modern life on wood. Our indebtedness is even greater to seeds. Civilization did not begin until men ceased to live an exclusively nomadic existence and began to acquire the habit of a permanent residence. This was brought about by ceasing to depend entirely on hunting and the gathering of wild plants and fruits for food, and by cultivating crops planted by man. In other words, civilization began when men began to collect and sow seeds. In order to reap the benefits of that labor it was necessary to remain where the seeds were sown until the plants grown from them produced another crop of seeds, and

so on, year after year. Without a fixed habitation, civilization, as we know it, would not be possible.

It requires only a little reflection to realize how closely men's lives are now related to seeds. The flour from which all breads and pastry are made is produced by grinding up seeds; all breakfast foods are prepared seeds; coffee and cocoa are derived directly from seeds; the nuts which we eat are seeds. The habits of whole nations are modified by the custom of drinking coffee. Books (one of them, *All About Coffee,* comprising 796 pages) have been written about the seed of the coffee plant. There is a monthly journal devoted exclusively to the seeds which are called nuts.

In a very real sense the skyscraper buildings of American cities may be regraded as a result of the habit men acquired of gathering and planting seeds and staying by until harvest, for without a fixed habitation and the civilization made possible by it we should have no skyscrapers—the "highest" expression of modern civilization!

A specialized stock exchange, known as the *New York Produce Exchange,* conducts daily transactions aggregating millions of dollars, most of which concern the buying and selling of seeds, especially cereal grains. In the United States the average yearly yield of cereal crops is as follows: Corn, 2700 million bushels; Oats, 1372 million bushels; Wheat, 833 million bushels; Barley, 241 million bushels; Rye, nearly 51 million bushels; Buckwheat, nearly 14 million bushels; Flaxseed, nearly 24 million bushels. The average annual wheat crop of the world is 3141 million bushels. The commercial seedsmen, of course, in many countries, transact a business involving millions of dollars annually.

Perhaps no one thing, except religion, has been a larger factor in the life of one-fifth the human race (in China) than the seeds of two plants, Rice and the Opium Poppy; from the latter the drugs opium and morphine are made. Many medicines are derived from seeds. Every day of our lives we depend upon these enclosed plant-embryos which, in their turn, depend upon the fertilization of a microscopic plant-egg-cell by a microscopic sperm in the ovary of a flower.

Where Spring Flowers Are Made

It is often a surprise to a non-botanist to learn that many of the early flowers of spring (*e.g.*, Wake Robin or Trillium, Dogtooth Violet, Hepatica, and others) are made under the ground. If, in October, one digs in the soil where these plants grow, he will find the flowers for the following spring more or less perfectly formed, but pure white. They remain underground all winter. When the soil is warmed by the next spring's sun the flower-stalk or the whole stem of the plant, as the case may be, resumes vigorous growth and the flower is lifted above the surface into the light, where it takes on its color and opens.

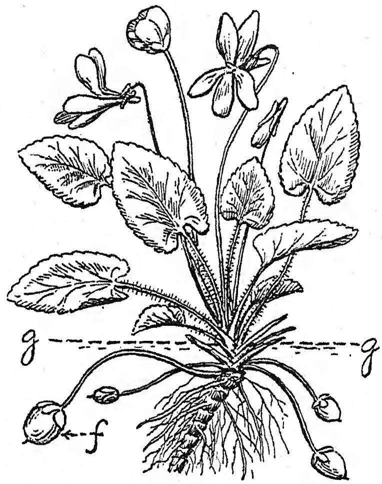


Fig. 65—A VIOLET (*Viola hirta*)
Showing fruits formed by cleistogamous flowers underground

How Plants Bury Their Bulbs

We know how the gardener buries the bulbs of the Daffodils and the Crocus in the fall, but many persons have never thought to inquire how the bulbs of wild plants become buried. When a seed of one of these plants germinates at or near the surface of the soil the lower end of the stem is sunk somewhat below the surface by the force of its growth in length. Roots develop, and near the close of each season changes and readjustments in their tissues take place in such a way that *the root shortens and becomes wrinkled.* Since the tip of the root is held in the soil more firmly than its upper part, that part and the young bulb (modified stem) are pulled down deeper into the ground. This is repeated year after year until the bulb may become buried from several to many inches. Everyone has noticed how closely appressed the rosettes of Dandelions, Plantain, Mullein, and other plants are to the ground. This is also the effect of contractile roots, which pull the main root and stem down into the ground, thus keeping the leaves close to the surface.

CHAPTER X

WHY WE HAVE SPRING AND FALL FLOWERS

IN THE tropics, trees are in leaf and plants are in flower continuously, but in temperate regions the change of seasons is marked by changes in vegetation. In the fall deciduous trees shed their leaves; biennial plants produce rosettes of leaves that hug the ground; herbaceous perennials die to the ground and pass the winter in the form of underground bulbs, corms, tubers, and root-stocks; annuals die completely, except for the seeds they have produced; trees and shrubs form buds which are dormant in winter.

With the return of spring, buds open and new leaves appear, biennials send up tall stems from the centers of their rosettes, bulbs and other underground parts put forth new growth, seeds germinate and produce seedlings. Some plants—the early spring flowers—burst into bloom at once (Pussy Willow, Maples, Alders, Magnolia, Trailing Arbutus, Hepatica, Trillium, Dog-tooth Violet, Crocus, Daffodils, etc.); others bloom in summer (Iris, Poppy, Sweet Pea, Roses, Blackberries, Spiraea, etc.); still others are "fall flowers" (Aster, Goldenrod, Chrysanthemum, Dahlia, Salvia, etc.). Some plants, such as Dandelions and certain Strawberries, are "ever-blooming."

What is the explanation of these differences? It is commonly taken for granted that the seasonal activities of plants are wholly due to the temperature changes that mark the change of seasons. Two botanists of the United States Department of Agriculture, Dr. Garner and Dr. Allard, made experimental studies to answer this question. They found that the difference is due chiefly to the fact that plants react differently to the differences in the length of day as the seasons change. Many kinds of plants were tested. Some were kept dark during a portion of long summer days, others were exposed to artificial sunlight from electric lamps so as to impose long "days" upon them. Thus, a Wild Aster, which

normally does not bloom for four months (122 days) when exposed to light all day during the long days of summer, was made to bloom in about one month (36 days) when allowed only seven hours of light each day. By shortening the length of the daily light period, Violets, Chrysanthemums, and Dahlias were made to bloom in midsummer. The Christmas-blooming Poinsettia developed its red leaves (*bracts*) in August when allowed not more than ten hours of light each day.

"In the light of these experiments there is no longer any element of mystery concerning the fact that when plantings of Cosmos are made at successive dates in early spring, a point is reached at which the plantings suddenly swing over from flowering in the spring to flowering in the fall. Cosmos begin to flower in the fall when the length of day has decreased to about twelve hours (sunrise to sunset) and, in the same way, it is no longer able to flower in the spring after the days become much in excess of twelve hours in length."*

In other words, some plants are *short-day plants;* that is, short days and long nights stimulate or favor the formation of flowers and are unfavorable for "vegetative" activities such as growth and leaf-formation. The early *herbaceous* spring plants (Crocus, Trillium, Dogtooth Violet, Hepatica, and others) begin to form their flowers as the days get shorter after the summer solstice. They are formed underground. The old stems and leaves die down each fall and the new stems and flower-stalks do not elongate, partly because the temperature is not favorable for growth. In the following spring the temperature again becomes favorable for growth, and the white flowers, completely formed, are lifted up into the air and light, where they assume their natural colors and open.

In the case of spring-flowering *woody* perennials (*e.g.*, Golden Bell or Forsythia, Japanese Witch-hazel, Pussy Willow, Maples, etc.), the shortening of the daylight period, after midsummer, induces the formation of flower buds, but the best light period for the *opening* of the flowers passes before the flower buds are mature, and their opening is also delayed by the onset of low temperature. The earliness of their flowering in spring

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* Garner and Allard, *Yearbook,* United States Department of Agriculture, 1920, page 385.

varies with the species, but also depends upon how soon the temperature rises to a point favorable for the given species.

The combination of best temperature and best light-period for the American Witch-hazel occurs in late fall, and that species is commonly called our latest fall flower. It has been facetiously called the earliest of spring flowers flowering ahead of time.

Iris, some Roses, Red Clover, and Hibiscus may be cited as examples of *long-day plants*. Hibiscus will not flower if exposed to less than seven hours of light each day for a series of days.

Ever-blooming plants have their vegetative and blooming phases so adjusted that they may continue both activities together, and are not as sensitive as seasonal-blooming plants to changes in the length of day.

The experiments of Garner and Allard also show that the formation of fall buds, and of rosettes by such biennials as Mullein, Thistle, and others, are determined by the change from long-day to short-day periods as summer passes into autumn.

Photo-periodism

The ability of plants to react to varying lengths of daylight is called *photo-periodism*. This knowledge has important practical applications. For example, florists have here a method by which the flowering of short-day and long-day plants may, out of season, be accelerated or retarded, as desired, by subjecting them to artificial "nights" or "days" of any desired length—by placing them in a dark chamber in seasons of normally long days or subjecting them to electric light in seasons of short days.

This knowledge has been of advantage in research work in genetics and plant breeding, where it is necessary to observe the behavior of plants in successive generations. By growing such plants as peas, cereal grains, and others under the electric light, two or even three generations (instead of one) may be brought to maturity and seed-formation in one season. Of course, this is possible only with plants whose seeds require but a short rest-period. The seeds of some plants require a much longer rest-period than those of others. Seeds of the Mangrove germinate at once, while still on the plant; seeds of many plants require a rest-period of several weeks or months before they will germinate.

CHAPTER XI

HOW FLOWERS GET THEIR COLOR

In speaking of the color of flowers we must distinguish between objective and subjective color. By objective color we mean a certain wave length of light—short as in violet, comparatively long as in red. By subjective color we mean the sensation produced on the observer when light of various wave-lengths and intensities impinges on the retina of the eye. The most striking illustration of subjective color is the color-blind person, who may be unable to perceive color at all, or unable to distinguish a particular color.

But we all manifest this subjective characteristic under certain conditions. Thus pure yellow, when barely visible, appears to us as violet when beside a very intensive yellow. The *sensation* of violet also results when we look at a blue whose blueness (chroma) has been diminished, but whose luminosity (intensity of reflection of light) has been increased. One who has photographed yellow flowers discovers that in some of them the basal part of the petals has different color value than the upper part —a difference that had not been noticed by the human eye. Possibly insects can detect colors in flowers (*e.g.*, ultraviolet) that the human eye cannot detect. The camera and spectroscope have revealed to us the fact that many red, yellow, blue, and white flowers (*e.g.*, Portulaca, Buttercup, Larkspur, White Waterlily) reflect ultraviolet more or less strongly.

Sunlight, as Sir Isaac Newton discovered, is a combination of the seven colors that compose the rainbow or spectrum. An object is red because it is so constituted that it reflects the red rays of a beam of sunlight but absorbs all the others. Each color of objects is similarly explained. A lily is white because it reflects all the rays of the sunbeam; a buttercup is yellow because it reflects only the yellow rays, absorbing all the others. An object is black because it absorbs all the colors of the spectrum.

The Anatomy of Color

Early spring flowers formed underground are white for the same reason that the dry air-roots of orchids (page 60) and autumn birch leaves are white, that is, no pigment has been formed and the light is reflected from tissue full of air. As soon as flowers are exposed to light various pigments develop. The blues and reds occur in solution in the cell-sap; the yellows occur as solid bodies (*plastids*) floating in the cell-sap, just as the green chlorophyll occurs in the form of chloroplastids.

In tulips, for example, the reddish and blue solutions are largely or wholly confined to the outer skin or epidermis of the petals, as one may easily demonstrate by peeling off the skin of a petal.

Yellow, green, and white plastids occur in the tissue between the upper and the lower epidermis. The result is a blending of colors, giving the most varied and beautifully delicate shades and tints; or a complete masking of the other colors by the deep blue of the epidermis. We recall Dumas's classical story, *The Black Tulip*. That color can never be realized, although some of the purples are so dark as to appear almost black. In yellow tulips there may be some pigment in the epidermis of the petals, but usually the color is confined to the middle tissue. In the brilliant leaves surrounding the flowers of *Poinsettia* the red color-solution is confined to the upper and lower epidermis.

Blue Roses

Certain classes of plants seem to manifest a wide variety of colors, shades, and tints. Thus, Poppies are red, violet, yellow, or white; Pansies are blue, yellow, or whitish; some Violets are, of course, violet, but some are yellow or white; Peonies may be red, white, yellow, or purple (a mixture of blue and red); Lupines are blue, white, or yellow; Roses are red, white, or yellow, in various shades and combinations. But certain groups of plants seem rigidly to exclude certain colors. "The rose is red, the violet blue," but not *vice versa*. Although the attempt has often been made to produce a blue rose, no one has ever succeeded—just as the seventeenth century Dutchmen never succeeded in producing a black tulip. The reason a blue rose has

never been produced is that blue has never arisen spontaneously in the Genus *Rosa,* and no blue flower of another genus has ever been found that will cross with a rose and so transfer its blue color to the latter. A breeder who could do this would doubtless thereby make a fortune.

Green Roses

Sometimes roses develop having green petals. Such freaks, "sports," or *mutants* (see page 98) result because, in the cell-divisions involved in making the petals, the factors that make foliage-leaves green persist, while those which normally make flower-leaves (petals) red, yellow, pink, or white, fail to develop. This occurs also in other plants.

Changes of Color

Many flowers change color with age. The blue flowers of Bachelor Buttons fade to white; the flowers of the Crimson Rambler Rose to an unpleasant pink. This has diminished the popularity of that rose. The florets of Alsike Clover (*Trifolium hybridum*), after being pollinated by bees, change from a pinkish cream to a crimson-pink and finally to brown.

It is common knowledge that the ovaries of many flowers change color as they develop into fruit (see page 68). The green tomato ovary changes to red or yellow, the green ovary of the orange to orange color; green apple ovaries to red or yellow. This change of color often occurs only when the ovary is exposed to sunlight while ripening. A greenish area on an otherwise red apple is usually caused by that part of the surface being protected from the sun by a leaf.

These color changes show that cells may possess potentialities which come to expression only with age, or when the environment is favorable, or under some external stimulus. Thus, when certain insects lay their eggs in the tissue of a green leaf the cells may form an *insect gall* that is *red.* These changes of color are expressions of chemical changes, involving the action of plant enzymes.

Hydrangeas have blue flowers when the soil is alkaline to a certain degree; pink flowers when it has a certain percentage of acidity. Intermediate soil conditions give intermediate colors.

CHAPTER XII

POLLINATION

Kinds of Pollination

We have seen that the purpose of flowers is to make seeds, and that this cannot be accomplished without the transfer of pollen from anther to stigma. There are various kinds of pollination as follows:

1. *Cross-pollination.* Of this there are two types:
   a. By pollen from another *seed-grown* plant of the same species (*e.g.,* Nasturtium and many other annuals).
   b. By pollen from another variety or species. This is *hybridization.* The resulting plants are *hybrids* (*e.g.,* flowers such as Iris, Chrysanthemum, Lilacs; fruits such as Tomatoes, Pears, Melons; vegetables such as Corn, Peas, Potatoes).

2. *Close-pollination*—from flower to flower of the same plant or from plant to plant of a *clonal variety* (*i.e.,* one propagated *vegetatively,* all the plants together constituting a *clone,* as in Apples and Grapes).

3. *Self-Pollination.* Some plants (*e.g.,* Sweet Pea) have showy flowers that are pollinated with their own pollen. More unusual are those plants, such as the Rock Rose (*Helianthemum*), which have large, open, showy flowers and also small, inconspicuous flowers that never open and are pollinated with their own pollen. The latter are called *cleistogamous* flowers, from two Greek words meaning "shut-in union" (of pollen and stigma). In some plants the cleistogamous flowers grow close to the ground (Violets) or underground (Milkwort, Hog Peanut, and Touch-me-not). Still other plants have only cleistogamous flowers (*e.g.,* one of the Sages, *Salvia cleistogama*). Still other plants have flowers that are cleistogamous at low temperatures (*e.g., Oxalis* and *Impatiens*) or in weak light (*e.g., Viola sepincola* and *Stellaria*), but not at higher temperatures

or in bright light. Cleistogamous flowers have very few pollen grains. Thus the Violet may have only one hundred, in contrast to several million in the Peony. After the seeds of the Violet are formed the flower-stalk, which formerly grew downward, now grows upward, lifting the ripened ovary well above the surface of the ground. The seeds are thrown out by the sudden, explosive opening of the ovary.

Fruits Formed Underground

The Peanut plant is an interesting case. Its flowers grow close to the ground and, after fertilization has taken place, a stalk at the base of the ovary elongates and the developing ovary is carried beneath the surface of the soil, where it matures into the peanut of commerce. Because of this strange behavior the plant has been given the specific name, *hypogea* (*Arachis hypogea*), from two Greek words meaning "beneath the soil."

Rapid Transit for Pollen

No aspect of botany has had a deeper popular appeal than the various methods by which pollen is conveyed from anthers to stigmas. Usually this must be accomplished within a few hours for, though Date pollen is said to remain viable from two to eighteen years, most pollen is short-lived, and many stigmas are *receptive* for only a few hours.

a. *Wind.* Practically all conifers (Pines, Hemlocks, etc.) and all grasses (Corn, Timothy, etc.) are wind-pollinated. By this method the chances that a given grain of pollen will not land on a stigma are so great that enormous quantities of pollen must be produced. A single blossom of Dandelion has been found to contain as many as 243,000 pollen-grains; one blossom of Peony over 3,600,000; a medium sized plant of Indian Corn over 50,000,000 grains. In one night in 1842 a shower of pine pollen fell in such quantities on the deck of a vessel in the harbor of Pictou, Nova Scotia, that it was (so the report states) "collected by the bucketful." Pines have been known to be pollinated by pollen that must have been carried as far as 400 miles. Pollen has been caught high in the air on specially prepared sticky plates carried by airplanes.

b. *Birds* (*e.g., Fuchsia* in New Zealand); Hummingbirds (Indian Mallow in Brazil, reported by Darwin).

c. *Water* (*e.g.,* Waterweed (*Elodea*) and Water-buttercup).

d. *Man* (*e.g.,* Vanilla). Vanilla is an orchid from the fruit of which (Vanilla "bean") the flavoring extract is derived. In its native countries (Mexico and Central America) it is pollinated by Hummingbirds and by *Melipona* bees; as other insects appear not to visit the flowers, plants when sent to Java flowered but produced no fruit. Professor Morren, of the University of Liége, Belgium, showed that good crops could be secured if the flowers were hand-pollinated. They remain open for one day only, and women and children become so skillful that they can pollinate 1500 to 3000 flowers between seven A.M. when the flowers open, and three P.M. when they close. An illness, "Vanillism," sometimes results from constant handling of the vines.

The Date Palm, which has the pistillate flowers on one plant and the staminate flowers on another, is commonly pollinated artifically by man. The Greek botanist, Theophrastus, described this practice, "the use of the wild fruit," over 2000 years ago, long before the explanation of it was understood.

Breeding experiments sometimes require the shipment of pollen. Owing to the loss of nearly all the Chestnut trees in the eastern United States by the Chestnut-bark disease and, since no effective treatment of diseased trees is known, experiments have been undertaken to breed a variety immune to the disease and bearing nuts that have the commercial value of American chestnuts. One project, now being undertaken by Dr. Graves, of the Brooklyn Botanic Garden, involves crossing the immune Japanese Chestnut with pollen from the American species. Since Japanese Chestnuts bloom fully two weeks earlier than the American species in the same locality, it is necessary to have the pollen of the American tree shipped from a locality having an earlier season—in the experiments here referred to, from Washington, D.C., and Wooster, Ohio.

In certain cases, after pollination, the fertilization of the egg fails, due to incompatibility. Northern Spy apples and Bartlett pears, for example, are self-incompatible (setting fruit only when self-pollinated), while Baldwin apples are partly self-compatible (fruitful with their own pollen).

CHAPTER XIII

PLANTS AND INSECTS

MOST flowers with showy petals or sepals are cross-pollinated by insects. Nearly all such flowers have *nectar glands* at or near the bases of the petals, and the insects visit the flowers to secure the nectar. Bees also visit flowers to get pollen, out of which they make honeycomb. It is a very significant fact that there were no flowers with showy petals on the earth until the geological age in which insects first appeared; then these flowers developed. Many crops (especially tree fruits) suffer greatly if the weather is too cold, rainy, or otherwise unsuitable for insect flight during the few days when pollen is being shed and stigmas are receptive. So important are bees to a good crop of various orchard fruits that the practice is sometimes resorted to

Fig. 66—BEEHIVES PLACED IN A PLUM ORCHARD TO INSURE POLLINATION OF THE TREES (BY THE BEES)

(After C. F. Kinman)

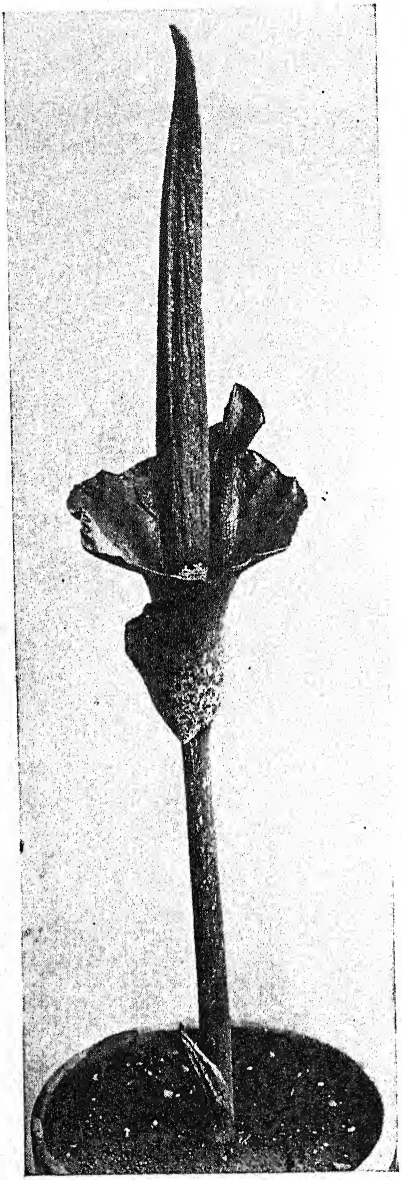

Fig. 67—FLOWER OF *AMORPHOPHALLUS RIVIERI*

Height nearly four feet

A malodorous relative of the Calla Lily. The stems and leaves appear after the flowering is over

of having beehives in the orchard to make sure that there will be plenty of bees for cross-pollination at blossom time (Fig. 66).

The Odors of Flowers

While there is some difference of opinion as to just how insects are attracted to flowers, there is evidence that this is one of the functions of odor. Odor is due to the presence of *essential oils*—odorous volatile substances which are waste products of the life-processes of plants. Those of flowers are called *attar* (*e.g.*, attar of Roses), in distinction from those of leaves. Attar is more complex than the essential oils of odorous leaves, and this it is that makes the odor of flowers more delicate than that of foliage. For example, the odor of the foliage of a Rose-leaf Geranium is due to *geraniol* alone, but the more delicate odor of a rose is due to geraniol plus seven or eight other volatile substances, whose odors combine with that of the geraniol to make the more delicate scent of the flower. Some observations indicate that these essential oils are used by the plant as antiseptics, and several of them are so used by man (*e.g.*, Eucalyptol and Oil of Cloves). It has also been suggested that the odors of many desert plants repel herbiv-

orous animals and thus save the plants in a region where grazing plants are scarce. One of the fleshy fungi has such a bad odor when its spores are ripe that flies are attracted to it as to carrion, and thus its spores become widely distributed by the flies.

Various species of *Amorphophallus,* a plant of the Old World tropics related to the Calla Lily and the Jack-in-the-Pulpit, have enormous flowers. In some species the "Jack" (*Spadix*) is three feet tall. A specimen of *Amorphophallus Titanum* from Sumatra is recorded with the funnel-shaped spadix so large that a man with open arms could reach only half way around its circumference. The plants give off an odor of carrion so penetrating as to fill a greenhouse or room when the pollen is ripe. It is believed that this flower is dependent on carrion-loving insects for pollination.

Do the Colors of Flowers Attract Insects?

For years it has been generally accepted as a fact that insects are attracted to flowers by their color. In fact, this has been held by some to "explain" the colors of flowers. Experiments in 1924 by Dr. Frank E. Lutz, of the American Museum of Natural History, and others have clearly shown that, "In addition to the colors which man can see, some flowers are ultraviolet, while others are not at all ultraviolet, and still others have an ultraviolet pattern. It has also been shown that flower-visiting insects can see ultraviolet as well as or even better than they can see the rays perceived as light by man." The result of his investigation is to add one more color to the list of those which plants use in facilitating the visits of insects, says Dr. Lutz; but he significantly adds, "if plants do use colors for such a purpose."

When we reflect that brilliant colors of plants are not confined to their flowers, that flower-visiting insects (bees and others) have poor vision but a well developed sense of smell, and that red, orange, yellow, and green flowers are commoner than those whose color ranges from blue to ultraviolet, and that flower-visiting insects do not see red to green as well as they do blue to ultraviolet, it seems reasonable, says Dr. Lutz, "to conclude that floral colors have developed simply as by-

products of the plant's metabolism;* that at most they are of only incidental and minor service to insects in finding flowers. . . ." This study illustrates how cautious we should be not to accept theory for fact, or in concluding that we have arrived at final truth concerning natural phenomena. The whole subject merits further investigation.

Pollination and Fig Culture in California

When the attempt was made to introduce Smyrna fig culture in California, the venture failed until Dr. Swingle, of the United States Department of Agriculture, sent from Europe the winter *Caprifigs* which contained the *fig-wasp,* the necessary agent of pollination, here called *Caprification.*

Results of Cross-Pollination

1. *Larger Fruit.* The fruit resulting from cross-pollination is usually considerably larger than that following close- or self-pollination. Thus, Dr. Coville, of the United States Department of Agriculture, by crossing plants that normally had extra large fruit, succeeded in increasing the size of Blueberries from the normal average of about the size of a green pea to $\frac{5}{8}$ inch in diameter.

2. *Mixing Inheritances.* It is common knowledge that each generation inherits from its parents. That which is inherited is, of course, passed on from generation to generation by the germ-cells (eggs and sperms). Therefore, when plants are crossed, "inheritances" from two different lines or strains are mixed in the fertilized egg, where they react on each other, producing new combinations which are *expressed* in the mature organism. That is one of the chief causes of the endless variation in living things. Probably no two were ever precisely alike.

What Is It We Inherit from Our Parents?

It is not uncommon to hear one say, for example, "He inherits his blue eyes from his mother." Such statements are only figures of speech. What one inherits from his parents are two small bits of protoplasm which unite to form the fertilized egg. These protoplasts contain certain *potentialities,* due to

* Transformation of matter within the plant.

their composition *and their past history.* How these find expression in the mature organism depends in large part upon outward circumstances. Blueberries, for example, resulting from a cross, can never be as large if the plants are grown on poor soil with insufficient water, as when they grow on rich soil amply watered. On the other hand, no amount of richness of soil and water could make Blueberries one inch in diameter without selection and cross-pollination. What we are, therefore—what a plant is—is the net result of its inheritance and its environment, the two reacting on each other. In other words, to secure the best results in breeding plants or animals we must practice *Eugenics* and *Euthenics*—one must be both well-born and well-placed or circumstanced (see page 102).

CHAPTER XIV

SEED DISPERSAL

PLANTS solve the problem of euthenics by producing many, many more seeds than can by any likely possibility succeed in producing new plants. These seeds are then scattered broadcast, in a chance sort of way. Some, as the Bible says, may fall on good soil and succeed, others will fall on poor ground and fail. The means of seed dispersal are numerous, and the devices of plants by which dispersal is secured are almost legion. Numerous books have been written on this one subject.

Among the various means of dispersal may be mentioned the generally *globular shape* of certain seeds (*e.g.*, many nuts). When such seeds fall to the ground they are apt to roll along and come to rest more or less scattered, thus reducing crowding and increasing the chances that each seed, after germination, may develop into another plant which, in turn, will produce more seeds.

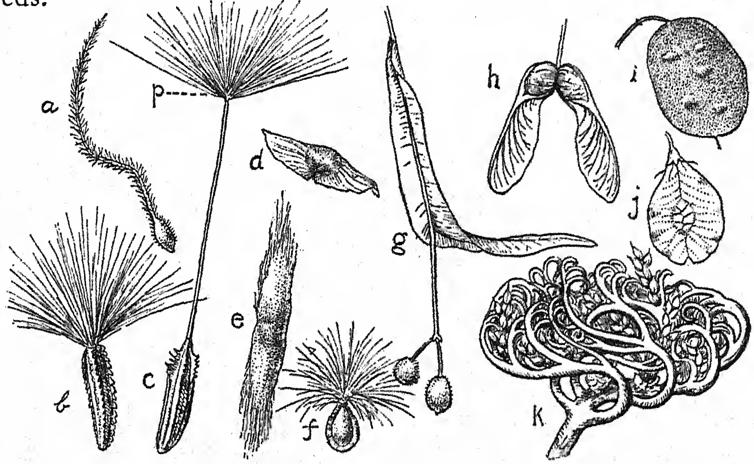

Fig. 68—DEVICES FOR THE DISSEMINATION OF SEEDS BY WIND

a, Clematis; *b*, Thistle; *c*, Dandelion (*p*, pappus, a modified calyx); *d*, Trumpet Creeper; *e*, Catalpa; *f*, Milkweed; *g*, Linden; *h*, Maple; *i*, Moonwort ("Honesty"); *j*, Elm; *k*, "Resurrection Plant" (*Anastatica*), the end of a branch bearing seeds is blown about.
(*k, after H. N. Ridley*)

The *bright color* of seeds (Magnolia, Climbing Bittersweet), or of fruit (Currant, Barberry, Tomato, Jack-in-the-Pulpit), attracts birds that eat the fruit and with it some, at least, of the seeds, which are not digestible, and so become widely disseminated.

"Hurrah!" wrote Darwin to Sir Joseph Hooker, "a seed has just germinated after 21½ hours in owl's stomach. This . . . would carry it God knows how many miles, but I think an owl really might go in storm in this time 400 or 500 miles."

Sticky Surface (Twinflower, Vervain, Salvia, Flax, Plantain, Evening-primrose), and *hooked appendages* (Burdock, Sticktights, Jimson weed). The sedge, *Carex canina,* was called *canina,* because it first came to the attention of man by being brought to Mr. S. T. Dunn, of Hongkong, adhering to the tail of his small terrier by the rough, toothed edges of its leaves. Ridley, who relates this, also notes that plants with hooked

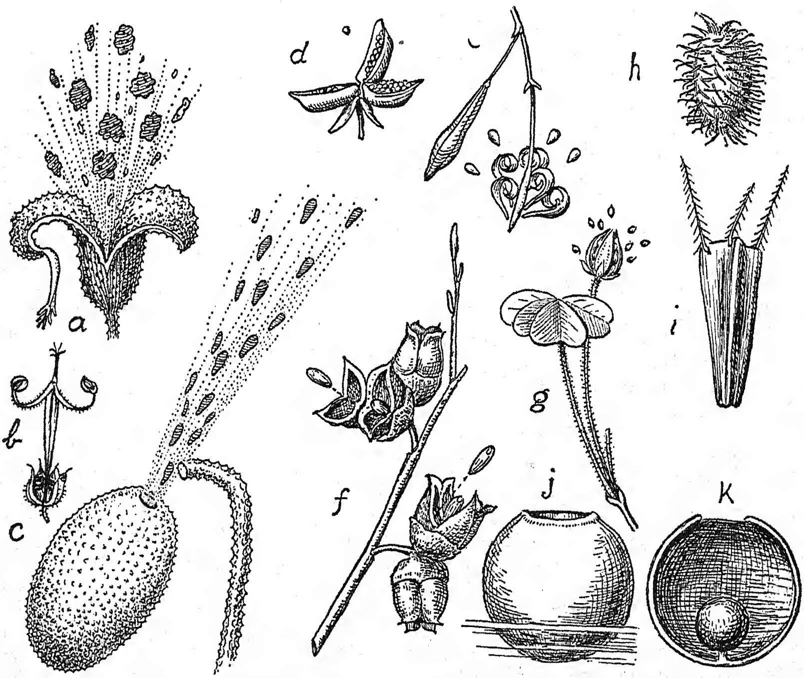

Fig. 69—DEVICES FOR DISSEMINATION OF SEEDS BY VARIOUS MEANS

a to *g* by exploding fruit: *a,* Cyclanthera; *b,* Geranium; *c,* Squirting Cucumber; *d,* Violet; *e,* "Touch-me-not" (*Impatiens*); *f,* Witchhazel; *g,* Sorrel (*Oxalis*). *h* and *i,* by hooked appendages: *h,* Cocklebur; *i,* Sticktight. *j* and *k,* by ability to float: *j* and *k, Hernandia* (*a, c, e, g, after Ulbrich; b, d, h, i, k, after Ridley; f, after Gray*)

fruits are most abundant in the Mediterranean region from Spain to Greece and Persia, their development there being explained by the fact that herds of herbivorous wild animals roamed the region in Eocene and Pleistocene times, though such animals are no longer found there. This illustrates the very long stretches of time that must be visualized in trying to explain the present geographical distribution of plants. Kerner says that about ten percent of all flowering plants are dispersed by fruits and seeds that have clawed or barbed processes.

Ability to float on water without becoming water-soaked insures dispersal for certain seeds, such, for example, as the Waterlilies. The number of seeds carried by streams is enormous; Egginton and Robbins, in 1920, reported that from four to nine million seeds were carried past a given point in twenty-four hours in a twelve-foot wide irrigation ditch, by water flowing only one foot per second.

Wind: Problems of aviation were solved by plants ages before they were by men. Thus innumerable plants have *winged seeds* which insure their being carried by the wind, often to considerable distances. Among familiar plants with winged seeds may be mentioned the Maple, Ash, Elm, Pine, False Acacia (*Robinia*), Tree-of-Heaven (*Ailanthus*), and others.

Numerous seeds have tufts of hairs which act like parachutes, keeping them up while the wind blows them along (*e.g.*, Milkweed). Cotton seeds are of this type, the surface hairs or fibers having developed to such an extent that we spin and weave them into cotton cloth.

In such plants as the Dandelion one seed occupies all the cavity of the ovary and the whole structure, which is a fruit, looks like and behaves like a seed, having the tuft of hairs on the surface of the ovary. In the Dandelion this tuft is a modified calyx, called a *pappus*. Orchids solve the problem by bearing millions of tiny, dust-like seeds, so simple that the embryo has not been differentiated at the time the seeds are shed and scattered.

Number of Seeds per Plant

The number of seeds produced by one plant is almost beyond belief. Darwin found that a plant of *Orchis maculata* bore

thirty seed pods, each having 6200 seeds, a total of 186,000 for the plant. Scott reported an orchid (*Acropera*) that bore 371,250 seeds per capsule, or about 74,000,000 per plant. Darwin calculated that the great grandchildren of a single plant of *Orchis maculata* would, if they all lived, "clothe with one uniform green carpet the entire surface of land throughout the globe." Orchid seeds are so small that, for example, in the Rattlesnake Plantain one seed weighed only 0.000,002 gram. Wallace found that 15,000 seeds of *Orchis maculata* were required to weigh one grain. Careful observations indicate that orchid seeds have been carried by the wind as far as 900 miles (Portugal to the Azores). Millions of them, of course, perish on such journeys.

Numerous plants *shoot* their young away. The case of the Violet has already been mentioned. The Balsam or Touch-me-not, suggestively named by the botanist, *Impatiens noli-me-tangere,* matures an ovary with definite stresses and strains in the tissues of its wall, so that if it is touched, ever so lightly, when mature, these strains are released and the ovary-walls suddenly separate and twist with much force, throwing the seeds to a considerable distance. In the Squirting Cucumber forces develop within the wall of the fruit which shoot the seeds out through an orifice in the stem end when the fruit falls away.

This subject of seed dispersal, like others mentioned above, has an extensive literature of books and magazine articles.

Seed Dispersal by Man

It is often very difficult to determine whether or not the plants growing wild in a country arrived there by natural means (that is, excluding human agency), for men are important agents in seed-dispersal, and men were great travelers before they were botanists. Thus reliable records (if there ever were any) are often lacking. For example, Ridley thinks it not improbable that hunters of the Old Stone Age (*Paleolithic*), though they had no agriculture, brought plants to Britain from Europe and Africa—doubtless by accident and not intentionally. According to Clement Reid, it seems certain that numerous plants that have "always" (*i.e.,* since there were any kind of records) been found growing wild in Great Britain were really brought there by men

of the New Stone Age (*Neolithic*), who probably came, with a crude agriculture, from Asia, bringing with their flax and grains various Asiatic plants which became established in Great Britain as weeds. Reid mentions Corn Cockle, Opium Poppy, Wild Cherry, Sticktights, Bedstraw (*Galium*), and others as "clearly weeds brought in by Neolithic agriculturists." The weed seeds (*e.g.*, Sticktights) came unintentionally, mixed with crop seeds, adhering to clothing or other objects, and in other ways. Red Poppies did not appear in England, according to Ridley, until Roman times.

When agricultural men occupy the country of non-agricultural aborigines, as when Europeans took possession of North America, they change the environment of the native plants on a vast scale, cutting down forests, plowing fields, and so forth, and the native plants are then replaced in such areas by foreign plants whose seeds have been brought in by accident or by intent. Thus the common Dandelions of North America were doubtless introduced by the early English colonists. Cacti, which are native American plants, were recently introduced into Australia and are now becoming established as "wild plants."

Economic Results of Seed Dispersal

One economic result of seed dispersal (*i.e.*, affecting man's activities and finances) is the scattering of weeds. Weed seeds are characterized by the ability to germinate quickly, even under what would be for other plants unfavorable circumstances. Weeds also grow, flower, and fruit quickly, thus getting each successive crop of seeds speedily and widely disseminated. In fact, it is in large part these characteristics that make a plant a weed, which is in reality only a plant which is always trying to insist on growing where *we* wish another kind of plant to grow. Various weeds, like the Dandelions, also produce two or more crops of seeds a season, with large numbers of seeds in each crop.

Foreign Menaces Among Plants

This ability to get themselves widely distributed in large numbers brings weed plants to distant places where they are, in a sense, unwelcome "foreigners." With plants as with men, some

foreigners are very welcome, while others are neither desired nor desirable. Among such menaces we may speak of:

The Yellow Peril, the Dandelions. It is a surprise to most Americans to learn that this plant was introduced from Europe. In fact, we should not say "this plant," but "these plants," for many if not most lawns contain two distinct species of Dandelion, the flowers of the two kinds looking pretty much alike. There are no greater pests in our lawns. They not only produce several crops of enormous numbers of seeds each year, but send down thick long *tap-roots* into the soil; these keep the plants supplied with moisture and stored food even in periods of prolonged drought. Moreover, the leaves commonly lie in rosettes so close to the surface of the ground (see page 71) that they are injured only slightly, if at all, by the lawnmower. The flowers are on very flexible stalks which bob up serenely and quickly when run over by the mower and then elongate more quickly than almost any plants around, so as to insure the dissemination of the seeds (fruit) with the slightest breeze.

White Man's Burdens (botanically speaking) include the White Daisy (really a wild Chrysanthemum, and like the Dandelion, a foreigner coming from Europe); the Devil's Paint Brush (of which there are several kinds, comparatively recent immigrants from Europe); the Japanese Honeysuckle, originally welcomed with open arms (in the shape of open garden gates) as an ornamental, but now becoming a serious weed in many places.

It is a characteristic of many plants and animals (Rabbits in Australia, English Sparrows in North America, and many insects injurious to trees and crops such as Japanese Beetle and Cotton Boll Weevil) that they become serious pests when introduced into a foreign country, though quite innocuous at home, owing largely, no doubt, to the fact that they have natural enemies at home which keep them in check.

Reforestation

The dissemination of the seeds of forest trees has a most important aspect in connection with natural and artificial reforestation. This depends, in part, on the fact that there are *tolerant* and *intolerant* species; that is, those whose young seedlings can tolerate shade and those whose young seedlings

cannot tolerate shade. Thus, a Pine forest is sometimes replaced by one of Hemlock because Hemlock seedlings can grow under the shade of pine trees. Pine seedlings are intolerant of shade, and therefore Pine is not likely to replace Hemlock in nature. Because of its intolerance, Pine is a satisfactory tree to plant in open places, such as the unforested watersheds of city reservoirs and water systems. Rhododendrons will grow under the trees of an open woods because they are tolerant.

Biological Results of Dispersal

It is necessary to understand seed dispersal before one can understand the many interesting puzzles about the geographical distribution of plants, which Darwin, in his *Origin of Species,* called the "almost keystone of the laws of creation." Dispersal, while tending to decrease the *struggle for existence* between the offspring of one parent, also increases the struggle among plants of different species, as when Plantain tends to crowd out grass. This is one of the great factors explaining the establishment of new species. Moreover, dissemination increases the chances of hybridizing, and hybridizing promotes *variation,* which is another fundamental factor in the evolution of new species.

When the Arctic Region Explored Us

For a generation or more man has been exploring the polar regions. But a million years ago or so the north frigid zone invaded the north temperate zone. During this period, known as the *Ice Age,* a vast continental ice sheet covered the northern part of North America, much as the ice now covers Greenland. In fact, there were four or five periods of advance and "retreat" of continental ice sheets.* Each period was an Ice Age separated from the others by an *interglacial period* of mild climate like the present. Possibly the ice sheet may not yet have "retreated" for the last time, so that we may now be enjoying only an inter-glacial period. When the ice advanced, the vegetation and animals were gradually driven south. Professor Ernst Antevs, by studying the fine laminations of clay in deposits

* It is thought that the ice may not have "retreated," as that word suggests, by the gradual melting back of its front edge, but that it may have broken up by melting over large areas with the gradual return of warm climate to the glaciated region.

laid down under water during the last Ice Age, has estimated that the "retreat" of the ice from its southernmost extension (approximately the latitude of the City of New York and the mouth of the Ohio River) required 25,000 to 30,000 years. Possibly a similar period of time was required for its advance. The migration of both plants and animals was, therefore, a gradual process, and adjustments to the slowly changing climate could fairly well be made. Of course, the migrations of vegetation during both the advance and "retreat" of the ice were accomplished chiefly by means of the dissemination of seeds and other reproductive parts.

As the ice began to "retreat" (*i.e.*, to melt faster than it advanced), the climate to get milder, and the plants to return northward, the Arctic species could finally become permanently re-established only in what are now the Arctic regions, and in the Arctic or sub-Arctic climate of the higher mountains. This explains how it is that on such peaks as Mt. Marcy in New York, Mt. Katahdin in Maine, and Mt. Washington in New Hampshire, there are found as many as fifty strictly Alpine species—plants which could not now reach or leave those summits by natural migration, because they could not live in the mild regions they would have to traverse in order to get to the sub-Arctic climate of higher latitudes. Among the more commonly known species found both in Labrador and near the higher peaks of the White Mountains are the Lapland Rhododendron, *Diapensia Lapponica,* Black Crowberry (*Empetrum nigrum*), and three or four species of willows.

The Floral Kinship of America and Japan

The flora of Japan is more closely related to that of northeastern North America than to that of its *nearer* Pacific coast. Professor Asa Gray explained this as resulting from the advance and "retreat" of the continental ice sheet. As the ice advanced the plants of the glaciated region migrated southward along the west coast of the Pacific and the west coast of the Atlantic oceans. As the ice melted away, the plants migrated northward and became "permanently" established as the "native" floras in the favorable climates of what are now Japan and northeastern America, the species being of the same genus or family.

CHAPTER XV

THE CYCLE OF LIFE

ONE of the common designs of classic Greek architecture is the "Egg and Dart," in endless repetition around a frieze. Its significance is, "Life and death—but not forever." The Greeks recognized this concerning human life; men come and go, but humanity continues. So it is in the plant world. Plants are continually dying but vegetation as a whole persists. What becomes of the dead plants? At first thought it might seem as though the earth's surface would be covered with dead plants, and the soil completely clogged with the roots of plants long since dead. Such, however, is not the case, as we very well know, for the dead plants and dead parts of plants decay.

What is decay? Timber in very old buildings does not, as a rule, decay. Sometimes, however, it is disintegrated by what we know as "dry rot," and dry rot is a fungus which lives by deriving its nourishment from the timber, secreting a fluid which digests the wood so that it may be taken in by the fungus as food. Dry rot is a kind of decay, and all decay is caused by plants (fungi and bacteria) which live on dead plants and dead plant parts. This is why leaves which fall in autumn do not accumulate indefinitely, year after year, on the forest floor. This explains also how the roots of dead plants disappear in the soil. They are caused to decay by *saprophytic* plants (see page 64), and so become converted into soil for yet other plants.

The cycle may be illustrated by tracing the carbon which enters the plant from the air as carbon dioxide in the process of photosynthesis (see page 36). The carbon, taken from this gas, is built up into carbon compounds (*e.g.*, sugar), and these are converted by the protoplasm into wood and other tissues of the plant. We may recover the carbon by transforming the wood to charcoal, which is pure carbon. But when the wood is burned up the carbon passes to the air in the form of carbon

dioxide again. A similar thing results in plant respiration, when oxygen unites with the carbon, and the resulting compound, carbon dioxide, passes into the air. A like transformation takes

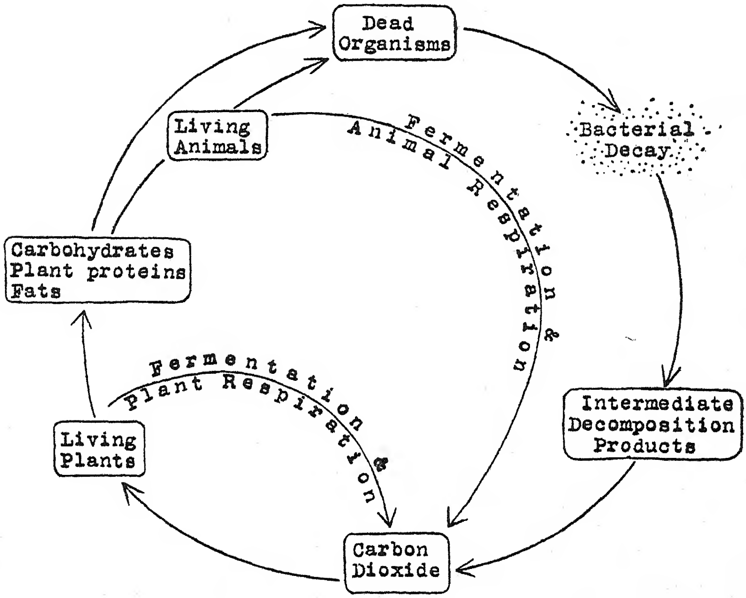

Fig. 70—THE CARBON CYCLE

place through decay, which also results in the formation of carbon dioxide. The gas may then be taken up by other plants (in photosynthesis) and the cycle repeated (Fig. 70). The soil is enriched by substances other than carbon, added to it when plant parts decay.

So we see that plants make their own soil and their own food, then live in the soil while they consume the food and make other plants. "Life and death—but not forever."

CHAPTER XVI

HOW WE CAME TO HAVE DIFFERENT KINDS OF PLANTS*

Two Points of View

NEXT to the beauty of plants the thing that impresses us most is their endless variety—so many kinds, no two exactly alike. How are we to explain these facts? At one time the majority of those who gave any thought at all to the subject accepted the explanation that the different kinds of plants and animals were "in the beginning" created as they are with all their bewildering diversity. God spoke, and it was so. To accept this explanation gives intellectual rest, but means the end of all science, for science is born of intellectual unrest. Moreover, science is primarily interested in "How." "Granted," says the scientist, "that the Creator made all things; what I am interested in as a scientist is, How did He do it? What *means* did He employ? What was His *method?*" To ask such questions is to endeavor at once to find the answers. Science is the study of method, and only persons of an inquiring mind ever become scientists. It is by search and *research* that knowledge is advanced. Without research we should have none of the comforts and (what are now considered) the necessities of modern life —telephones, X-rays, radium, modern sanitation and medicine, improved flowers and vegetables, and above all, comparative freedom from the shackles of ignorance, superstition, and bigotry, which make life today so infinitely sweeter and better than in certain periods of past history.

Variation

When we come to analyze the problem of different kinds of plants we are confronted with two facts of the first order of importance, namely *variation* and *heredity*. "Our ignorance

* See "Heredity and Variation" in this *Series*.

of the laws of variation is profound," said Darwin in his *Origin of Species*. And again, in the same book, "The laws governing inheritance are quite unknown." Our ignorance concerning both matters is still profound, but our knowledge is much greater and much more exact than it was in Darwin's day, thanks to the painstaking experimental studies of DeVries, Mendel, and a host of other investigators. In a book of this size we can give only the barest outline of essential points on both subjects. But, since the foundation of our knowledge of the principles of variation, and especially of heredity was laid in the study of plant life, the matter should not be wholly passed over here.

Variation is of two kinds, *quantitative* and *qualitative*. For example, we may take such a characteristic as the size of a White Oak leaf. The mature leaf has never been known to be as small as one-sixteenth of an inch in length, nor as long as three feet. There are extremes in size and also a certain *average length* which the majority of White Oak leaves will closely approximate. Any leaf may be larger or smaller than the average within the known limits, but it always maintains certain characteristics, so that, whatever its size, a botanist would always recognize it as a White Oak leaf, differing from the leaf of a Red Oak or a Willow Oak. We say that the size *fluctuates* about a middle or *mean* (which is the average of the extremes). That is quantitative or *fluctuating variation.*

The cause of fluctuating variation cannot always be determined. Rich fertilizing and abundance of water and light favor larger size, while sterile soil, drought, and excessive shade favor small size (in the Oak). In other words, fluctuating variation seems to be very closely related to surroundings or environment. The character fluctuates as the environment fluctuates, but the *expression* (large or small leaf, as the case may be) does not persist in the next generation; no *fundamental change in the germ-cells has been involved.* The botanist says there has been a change in the *phenotype* (in the way the thing looks), but not in the *genotype* (the inner essence of the germ-cells).

Giants and Dwarfs

Qualitative variation, on the other hand, is not merely a case of more or less; it involves the appearance of something new.

For example, numerous species of plants (and of animals) have produced dwarf forms (*nanism*), or giant forms (*gigantism*). Thus, in the shrub *Viburnum* we have *Viburnum opulus* (the normal type) and *Viburnam opulus nana* (the dwarf form). In the Solomon's Seal we have the normal type, *Polygonatum biflorum*, and *Polygonatum biflorum forma immensa,* which may reach a height two or three times greater than the normal form ever attains. Both the dwarfs and giants, as to size, fluctuate about a new mean, and this characteristic is inherited from generation to generation. The Evening Primrose, *Oenothera Lamarckiana,* has, under our eyes, produced by qualitative variation, *Oenothera gigas.*

Fig. 71—HUGO DEVRIES
Dutch botanist, and author of the Mutation Theory

The Origin of Moss Roses

Previous to about 1696 Moss Roses had never been reported. Then a plant of this character was found growing in Carcassonne, south France. It probably arose as a bud-sport from the Cabbage Rose (*Rosa centifolia*). An entirely new feature had appeared in roses, fluctuating about its own mean. Such qualitative variations were called, by DeVries, *mutations,* or *elementary species.* They may involve a fundamental change in the sperm or the egg or the fertilized egg-cells, as in the production of the Giant Evening Primrose. But *vegetative mutations* (like the Moss Rose) are also well-known, where the fundamental change took place in the cell or cells which give rise to a bud. Since 1696 the Moss Rose has been observed to arise twice—once in 1801 in England, and again about 1843 in France, in both cases as a *bud mutation.* The Navel Orange arose in the latter way. Plants arising by mutation are called *mutants.*

The cross-fertilizing of plants is known to be favorable to mutation, and it may be experimentally induced by exposing the

germ-cells to radium rays, X-rays, or other special treatment. Gager and Blakeslee (in 1927) were the first to induce mutation in plants by exposing the germ-cells of the Jimson Weed (*Datura*) to radium rays.

Thus we see that although, generally speaking, "Like begets like," still there are always non-inheritable quantitative differences and inheritable qualitative differences from generation to generation. The most important contribution to our knowledge of the laws of variation, in modern times, if not in all time, was made by the Dutch botanist, Hugo deVries, in his two-volume work, *Die Mutationstheorie* (*The Mutation Theory*), 1901 and 1903, and in numerous other books and articles.

Heredity

Many exhaustive treatises have been written on both variation and heredity, but enough has been said here to enable the reader to see how new forms of plant life originate. Many forms arise only to perish with the first generation, for they cannot withstand the climate, or are unable to perform some necessary function. Thus we have albino (white) mutants of Indian Corn and other plants. They are totally devoid of chlorophyll and so cannot manufacture plant food. Being unable to obtain it from other plants, as parasites do, or to live as saprophytes, they perish before coming to maturity, as soon as they have exhausted the elaborated plant food stored in the seed.

We have already noted that a plant's inheritance is a definitely constituted amount of protoplasm from egg and sperm or other reproductive cells. The *expression of the inheritance* depends upon the environment. Thus a giant form will be a larger giant in rich soil with proper water, light, and temperature, than in poor soil with inadequate water, light, and temperature. By *heredity* we mean the genetic relationship between two organisms.

Peas and People

On page 97 we referred to the inheritance studies of Mendel. Mendel was an Austrian monk, who undertook the breeding of peas in the monastery garden at Brünn as an avocation. He

conceived the idea, which no previous breeder had apparently even thought of, much less acted upon, namely, to confine his attention in a given experiment to a *single pair* of characters, to follow the results of his first cross through several generations, and *to count his results,* so as to give them a precise, mathematical expression. In fact, Mendel's work was the first quantitative experimental study ever made of heredity. His results were published in 1866. His problem was to ascertain just how a given characteristic is inherited in the first *and subsequent* hybrid generations following a cross. He chose the common garden-pea because it possessed clearly differentiated pairs of characters (*e.g.,* wrinkled *vs.* smooth seeds; yellow *vs.* green cotyledons; tall *vs.* dwarf stems, etc.). Also, it was easily grown, produced seeds in a short time, was easily protected from foreign pollen, etc. Without further details, as to method, it may be noted that Mendel discovered three fundamental laws of inheritance:

Fig. 72—GREGOR MENDEL

Author of the most fundamental contribution ever made to our knowledge of heredity

Mendel's Laws

1. *Law of Dominance.* When two *pure-breeding* plants differing as to a given pair of characters (*e.g.,* wrinkled *vs.* smooth seeds) are crossed, the plants of the *first filial generation,* which Mendel called the F_1 (pronounced "F one") were all alike as to the given character; that is, the seeds were all smooth. Such characters Mendel called *dominant;* the contrasting character (wrinkled) he called *recessive.*

2. *Law of Segregation.* When a plant of the F_1 generation is self-pollinated, part of the seeds of the second filial generation (F_2, pronounced "F two") are wrinkled and part of them smooth, provided the environment has not been essentially al-

tered. It is *the golden rule of experimenting* to alter but one condition at a time. But here is where Mendel did what no one had ever done before—he counted the number of seeds of each kind and found that they occurred in the ratio of three to one (3:1), that is, three-fourths of them had the dominant character of smoothness, and the other one-fourth the recessive character, wrinkled.

But he did not stop with the F_2 generation. By self-pollinating the plants of that generation he found that the smooth seeds of the F_2 were not all alike. One-third of them were *pure* for smoothness, so that all the seeds of their descendants were smooth. But the other two-thirds produced both kinds of seeds and again in the proportion of three smooth to one wrinkled. The F_2 plants with (recessive) wrinkled seeds, when self-pollinated (*selfed*) gave rise only to plants with wrinkled seeds.

Thus we see that, when the germ-cells of the F_2 generation plants were formed, the pairs of *factors* for the pairs of characters "wrinkled" and "smooth" were separated, and when the next fertilization of eggs by sperms took place these factors again combined *according to the mathematical laws of chance,* giving a 3:1 or really a 1:2:1 (pronounced, "one, two, one") ratio. This is the law of segregation. The factors in the germ-cells corresponding to the characters of the plants are called *genes,* from the same Greek word from which *genetics* and *genesis* are derived. "You nor I nor nobody knows" the real nature of a gene.

3. *Law of Independent Assortment.* When two pairs of characters (*e.g.,* smooth *vs.* wrinkled seeds and tall *vs.* short plants) were studied together, Mendel found that the pairs behaved independently of each other, both giving the 3:1 (1:2:1) ratio in the F_2 generation.

One should not get the impression that this is, by any means, all there is to *Mendelism.* This is only a simple illustration of cases, showing how three fundamental laws of inheritance were ascertained by the simple method of breeding garden-peas.

The great importance of these results is recognized at once when we realize that the Mendelian laws apply to people as well as to peas. In fact they apply throughout the plant and animal kingdoms.

Genetics and Eugenics

The study of heredity by the experimental and statistical methods constitutes the science of *Genetics.* It is a "pure" science; that is, it is pursued primarily for the purpose of increasing our knowledge of natural laws, without any immediate interest in the applications of those laws to meet the so-called "practical" needs of daily life.

When the laws of genetics are applied to practical problems of plant and animal breeding, and are studied further with special reference to their utilization in breeding, we have the "applied" science of *Eugenics,* which is concerned with being "well born," as the word etymologically means. In the popular mind the word eugenics applied to man is thought of chiefly as the breeding of a superior human race; but it also applies to the breeding of plants and animals.

Euthenics

From what has been said here and under the heading Heredity (see pages 84 and 85), it should be clear that success in life depends upon being well born (eugenics) and well placed (euthenics). Both factors are essential, and the principle applies to plants, lower animals, and men. There is no use in sending to college a boy or girl not endowed with the capacity for intellectual success. No program of social service or social regeneration can succeed if drawn up in disregard of either of these two factors. The subject has been considered so important that Vassar College has established a special department for the study of euthenics.

Plant Breeding

The men of the Old Stone Age and the New Stone Age (our Paleolithic and Neolithic ancestors) utilized largely such plants as they found growing wild. The wild plants were constantly varying, and from time to time sports or *mutants* (see page 98) appeared which had characters superior to the average. In some cases, no doubt, these more desirable forms were chosen for seeds or vegetative propagation. We know that the American Indians understood the advantage of selecting the

By permission of North Dakota Agricultural Experiment Station

Fig. 73—PLANT BREEDING PLOTS FOR POTATOES, OATS, AND BARLEY

finest ears of corn for seed and taught this to the white settlers in Massachusetts. It is not difficult to see how, in this way, any given kind of cultivated plant (Indian Corn, Flax, Wheat, etc.) came to be a mixture of types or varieties. The interbreeding of these varieties, resulted in further complicating the strain. DeVries has pointed out that the Cocoanut Palm, on which the life of the inhabitants of the Malayan region is so fully dependent (for food, drink, cordage, mats, oil, drums, dwellings, ornaments, etc.), has more than fifty distinct kinds, varying in different ways in respect to their useful qualities.

DeVries, Shull, and others have shown experimentally that a field of ordinary Indian Corn is composed of many complex hybrids, which have been produced by the natural crossing (by pollination) of many mutant varieties or elementary species.

What Eugenics Did for Timothy

Dr. Herbert John Webber, while at the New York Agricultural Experiment Station (Cornell University), identified from among 17,000 individual plants of Timothy grass several hundred distinct varieties, and selected 200 of these for breeding experiments, propagating each type vegetatively (by bulbs) in a separate row, finding "wonderful differences in type"—dwarfs, giants, heavy yielders, light yielders, early and late blooming, large and small heads (inflorescences), etc. As Dr. Webber states: "Through many years and over millions and millions

of acres, among countless billions of plants, these variations have been accumulating, with no attempt having been made to isolate them and use the best for the foundation of improved races for cultivation. Is it any wonder, then, with this great accumulation of material, that by selecting the best variations we get races that yield nearly double the product obtained from the mixture of all sorts of types?" Dr. Webber obtained over seventeen new sorts which gave an average increased yield of 36.6 percent over ordinary Timothy. Estimating the annual value of the Timothy hay crop of the United States at over $249,000,000, this increased yield would mean adding over $90,000,000 to the value of the annual crop.

We hear a great deal of the commercial gains resulting from research in chemistry and physics. Quite as impressive figures could be cited concerning the financial gains from plant breeding and other aspects of botanical science. This is one reason why botanical research merits the most generous financial support.

Although in some cases men have selected their plants with reference to perpetuating their valuable qualities during the centuries of their cultivation, in other cases it seems equally certain that while both semicivilized and civilized men have selected, such selection was not made with reference to breeding. They have, for example, selected the largest or most luscious fruits *to eat,* saving the poorer specimens for seed. Throughout all this earlier period, the *production* of new forms was left to Nature. Man's work was confined to *collecting.*

The first man to recognize that our cultivated plants are mixtures of different varieties was probably the Spanish botanist, Lagasca (1776-1839). While visiting a friend on the Island of Jersey, he noted that the plants in a wheat field were not all alike. Apparently no one had ever observed this before. Lagasca pointed out as many as twenty-three distinct sorts in the field. His friend, Colonel Le Couteur, saved the seeds of what appeared to be the best of these twenty-three varieties, and in the course of a few seasons (about 1830) had enough seed of this origin to sell. He called it "Tolavera de Bellevue." It is still one of the most commonly cultivated varieties in France. A number of the best varieties of grain have had a similar origin, several in America.

CHAPTER XVII

GREAT PLANT BREEDERS

The First Hybridizer

THE modern practice of hybridizing as a means of artificially producing new forms began with the German botanist, J. G. Koelreuter (1733-1806), who is credited with having produced the first plant hybrids, about 1761. From that time the practice of plant breeding rapidly developed. From the practical point of view, the English horticulturist, Thomas Andrew Knight (1759-1838), is recognized as the "father of plant breeding by crossing," having urged that method as early as 1806. The method was greatly stimulated by the discoveries of DeVries, Mendel, and other pioneer geneticists, and in recent years has approached more and more to an exact applied science, based on the pure science of genetics.

Origin of the Sugar Beet

Among the great plant breeders with whose names and work everyone should be familiar are André de Vilmorin (1776-1862) and his son, Louis de Vilmorin (1816-1860), two Frenchmen, proprietors of the oldest seed growing and distributing agency in the world. The father, André (not Louis as is commonly stated) projected (in the breeding of wheat and oats) the method of "selection" or "progeny test," which consists in com-

Fig. 74—JAKOB GOTTLIEB KOELREUTER

German botanist

One of the first to explain the purpose of nectar in flowers. He produced the first plant hybrids

paring the progeny of a large number of individual plants and choosing the best for breeding. This principle was applied by both father and son to increase the sugar content in the common beet from 6.2 percent to over 16 percent, thus producing the "sugar" beet. This highest percentage was attained in 1861—the year after the death of Louis. The yield varies from about 2500 to more than 7700 pounds of sugar per acre, depending, in part, upon method of cultivation. (See pages 37 and 38.)

Previous to André de Vilmorin the method of selection was employed in animal breeding, but it was he who first systematically employed selection in plant breeding. This service alone places him near the top of the list of plant breeders.

The Greatest Plant Breeder

Victor Lemoine (1823-1911), of Nancy, France, has been called the greatest plant breeder ("creator") the world has ever seen, "measured not alone by the number of novelties, but also by their intrinsic value to the gardens of the world." Says one of his biographers: "Not a person who grows plants in a garden but what at one time or another has handled something that was the product of this master craftsman. . . . Victor Lemoine accomplished, in fully a score of different lines, results that in each would have sufficed to build the reputation of any one man." It would require several pages of this book to give even a list of his productions extending over a period of sixty years. It was he who produced (in 1876) the first double-flowered horticultural variety of Lilac (*Syringa*) by crossing a double-flowered bud-sport of *Syringa azurea* (*S. azurea plena*) with pollen from a natural species (*Syringa oblata*) and from several garden forms.

Lemoine and his son produced over twenty-five valuable varieties of Lilac, and numerous varieties of Deutzia, Astilbe (the florists' Spiraea), Gladiolus, double tuberous Begonias, Fuchsia (many varieties), Peonies, Chrysanthemums, the *Hydrangea paniculata grandiflora* (in 1866), and many others.

A Great Breeder of Roses

Dr. Walter Van Fleet (1857-1922), of the United States Department of Agriculture, was one of the greatest of modern

breeders of roses. His productions included the American Pillar, Silver Moon, Bess Lovett, and many others. "Strawberries, gooseberries, corn, tomatoes, peppers, cannas, gladioli, geraniums, honeysuckles," says his biographer, "felt the touch of his magic hand in improvement," but "he shunned notoriety."

Origin of the Concord Grape

Ephraim Bull, produced the famous Concord Grape, which arose as a seed mutant from a single seed of the wild grape

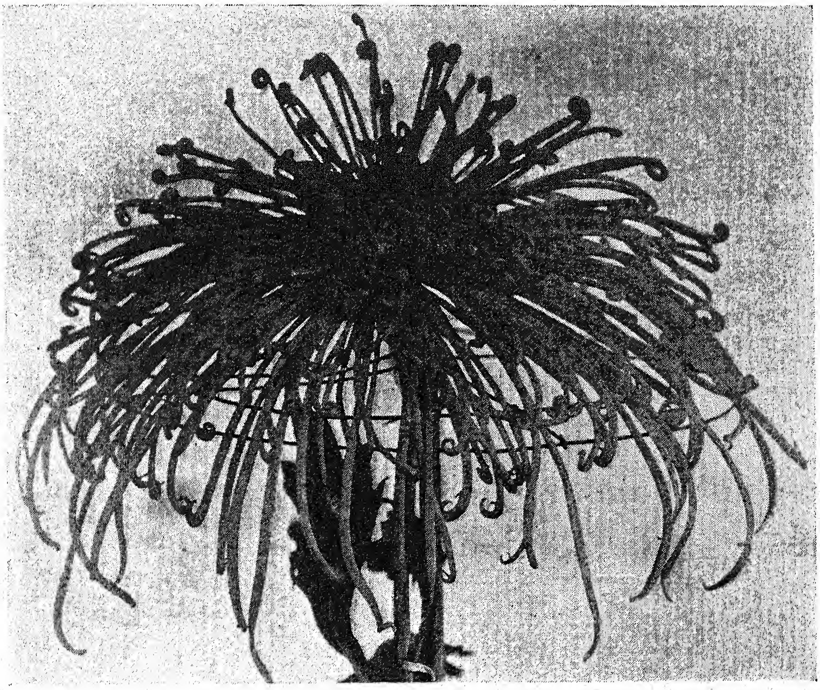

Fig. 75—A VARIETY OF JAPANESE CHRYSANTHEMUM—*UII NO SATO*
The largest form of the medium tubed variety. Diameter 10 inches
(*After Seijiro Sugiyama*)

(*Vitis Labrusca*) at Concord, Massachusetts, in 1843, bearing its first fruit in 1849.

A Hundred Thousand Dollar Tulip

In Japan are found the most famous breeders of Iris and Chrysanthemums, and in the Netherlands (Holland and other

provinces) the most famous breeders of Tulips and other bulbous plants. Every reader possibly knows of the "Tulip Mania" in Holland (1634 to about 1638), when speculation in bulbs became as wild as speculation is now (at times) in other "securities" on the Stock Exchange. A record price of 13,000 florins (equal to about 260,000 florins today, or, at approximately forty cents per florin, 104,000 American dollars) is reported to have been paid during the mania for one bulb of the variety "Semper Augustus."

Breeding Better Wheat

In 1906 a man in Kansas held in one hand a few grains of wheat—all the "Kanred" (Kansas red) wheat there was in the world. It had not yet been named. The seeds came from a single head selected from the crop of a Crimean variety introduced into the United States from Russia in 1900 by the United States Department of Agriculture. This head was one of 554 heads chosen from a large number. The seeds of each head were planted in a single row, and 451 of these rows were deemed worthy of being harvested, each row separately. The second year's strain was carefully studied as to hardiness, earliness, and other characters. This was continued for several years, the seeds being tested for milling and baking qualities. In 1919 the wheat crop of the country suffered badly from a disease known as *rust,* and it was observed that Kanred was notably resistant to both Orange Leaf-rust and Black Stem-rust. Moreover, Kanred was found to yield 4.5 to 4.7 bushels per acre *more* than other varieties. More than 20,000,000 acres of hard red winter wheat are grown annually in the United States, and by 1924 over 4,000,000 acres of the new variety, Kanred, were harvested (approximately 80,000,000 bushels)—all of this vast crop, having a value of several million dollars, derived from the handful of grains so carefully studied and handled fifteen years before.

This result was obtained by H. F. Roberts, the professor of botany of the Kansas Agricultural College, and his co-workers at the Experiment Station. More recently, other varieties (*e.g.,* Blackhull) have been developed with the good qualities of Kanred, but with stiffer straw, so that the plants

stand up better (do not "lodge") in wet seasons or on rich ground.

An equally impressive story could be told of the work started on the Dominion of Canada Experimental Farms at Ottawa by Dr. William Saunders, and completed by his son, Dr. Charles F. Saunders, about 1909, in producing the now famous "Marquis" wheat, grown widely in North America and Europe. Kanred and Marquis wheats have increased the yield and improved the quality of bread of many millions of people, including the reader of these lines, who may, perhaps, never before have heard of their names, or of the names of either Dr. Roberts or Dr. Saunders.

The work of all these and other plant breeders serves to emphasize the fact that the science of botany is something more than the study of spring posies, as many people still imagine.

Pure and Applied Science

Important as are the results of the great plant breeders, we should never lose sight of the fact that their labors would have been quite impossible had it not been for the earlier studies in "pure science" of Camerarius, Koelreuter, and others who interpreted the flower and the functions of its various parts merely for the satisfaction of finding out and knowing how. "Pure science," said the great French physiologist, Claude Bernard, "has always been the source of all the riches acquired by man and of all his real conquests over the phenomena of nature."

CHAPTER XVIII

DARWINISM AND EVOLUTION

What Plant Breeding Did for Darwin

THE universally recognized result of plant breeding is the production of new and better flowers, fruits, vegetables, farm crops, and other economic plants. But it had one result more far reaching than those which affect our palates and purses. It gave Charles Darwin (1809-1882) the key to the solution of one of the most baffling questions man ever tried to answer about the plant and animal world—namely, the problem of the origin of species. Professor Henslow (Darwin's teacher) pronounced it as baffling as the problem of the origin of evil.

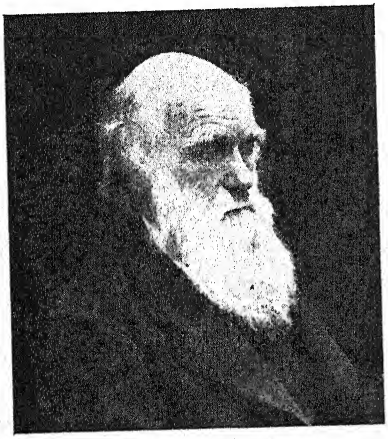

Fig. 76—CHARLES DARWIN

His *Origin of Species*, one of the greatest books ever produced, has given direction to scientific and philosophic thought from its publication in 1859 to the present

"In considering the origin of species," says Darwin (in the introduction to his book of that title), "it is quite conceivable that a naturalist . . . might come to the conclusion that species had not been independently created, but had descended like varieties, from other species." In the first chapter of the book he says, "And if we reflect on the vast diversity of the plants and animals which have been cultivated and which have varied during all the ages . . ." And then he proceeds to "reflect" for fifteen chapters occupying 502 pages in the first edition (1859) of the *Origin of Species*—one of the greatest books ever produced. The great botanist, Sir Joseph Hooker, pronounced it one of the hardest to read he ever tried.

Brief Outline of Darwinism

In barest outline, Darwin's theory as to the *method* by which new species arise in nature by descent from pre-existing species is as follows: From time to time, owing to causes not well understood, new characters appear in plants. That is *variation.* Some of these new characters may be passed on from generation to generation by *inheritance.* Certain forms thus acquire characters fit to survive in the given environment; others are less fit or not at all fit to survive. All the individuals contend or *struggle with each other* for food, water, light, and room to grow, and all of them *struggle against adverse conditions of environment,* such as drought, too much shade, too little room, too low or too high temperature. This contest with adverse conditions or superior neighbors was called by Darwin the *Struggle for Existence.* The result of it is the *Survival of the Fittest,* since the less fit perish. Herbert Spencer called it *Natural Selection.* Since "Nature," personified, is conceived in the rôle of a breeder *rejecting the unfit,* it has been suggested that a more accurately descriptive term would be "Natural Rejection." In this way new forms or species of plants and animals become established. Thus we see that a thoughtful consideration of the process of plant and animal breeding led Darwin to formulate the most satisfactory theory ever suggested up to his time as to how new species arise in nature.

Darwinism Today

In the light of investigation since Darwin, much of which was directly stimulated by his writing, it has been necessary to restate the theory in more modern terms, but in its essential points it still stands as the most satisfactory explanation of the origin of species, and as one of the most stimulating and fruitful ideas ever elaborated by the human mind. The last sentence of Darwin's *Origin of Species* is as follows:

"There is a grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being evolved."

Evolution: What It Is Not

The process by which new species are derived *by descent with modification* from existing species is a form or aspect of evolution, but "evolution" and "the origin of species" are not synonymous terms, for evolution is a much larger conception than that. In particular, evolution does not mean that men descended from monkeys. That idea originated with ignorant or bigoted opponents of the idea of evolution. Neither Darwin nor any other student of evolution ever taught it. It seems strange that it is necessary to emphasize this point so many, many years after the publication of Darwin's *Origin of Species.*

Also, the evolution of species does not mean that one species becomes transformed *into* another, but that new forms (varieties or what not) arise *out of* other forms, while the original form or species may continue to exist beside the new form. The Cabbage Rose, noted on page 98, did not "turn into" the Moss Rose; the latter came from the former by descent with modification. Both forms still exist.

Evolution: What It Is

All students of natural phenomena are now agreed that the present *condition of the universe,* in every detail, is the direct outcome or result of its past condition. This means that if we had a complete description of the universe at the present moment, and if our intellects were able to comprehend it, we could predict what the condition would be at the next moment. Every event stands in the relation of *effect* to preceding events and of *cause* to following events. When we say that events occur "by chance" we merely acknowledge that we do not know all the antecedent facts. Nature is uniform in her operations and does not play tricks with us.*

Moreover, the condition of the universe is never precisely alike at any two consecutive periods of time. Nothing is constant but constant change. It is this conception of the universe to which the term evolution is applied. It designates the processes by which planets and stars came into existence and

* Some physicists are now suggesting that the law of cause and effect may not hold in the new sub-atomic physics.

gradually reached their present condition and relation to each other; the processes which have resulted in the origin and present condition of our earth, the origin of different kinds of matter (chemical elements and compounds), the origin of plants, lower animals, and man, and the processes by which the plant and animal kingdoms have reached their present state of existence, and by which language, culture, and all human institutions have developed.

When the non-living world is in mind we speak of *Inorganic Evolution*: when referring to the world of living organisms (plants and animals) we speak of *Organic Evolution.* Organic evolution refers, not only to the origin of species, but to such broader problems as the origin of plant families; the processes by which the present geographical distribution of plants came about; the processes by which the various plant organs (flowers, stamens, ovaries, etc.) originated and gradually acquired their great diversity.

Evolution Is a Fact, Not a Theory

That the present condition of the universe, including the world of plants and animals, did come to be as it is by a series of gradual changes through the operation of the law of cause and effect, no scientist now questions. In other words, *evolution is regarded as a fact.*

As to the *method of evolution,* we have only hypotheses and theories based upon facts. We cannot be dogmatic as to the method because our knowledge is too limited. The essential thing is that we shall recognize our limitations in this respect and hold our minds open and unprejudiced, ready to revise our hypotheses and theories at any time in the light of sufficient new knowledge indicating the necessity for such revision. It is this attitude of mind, combined with the urge for unceasing search for new knowledge, and the continual testing of our hypotheses and theories in the light of new facts that marks the scientific type of mind. A scientist is not so much a man who knows, but a man who is continually striving to learn. As the writer has said elsewhere, the essence of science is the endeavor to ascertain by the best method that which is most worth knowing.

Evidences of Organic Evolution

Among the facts which have led men to formulate the conception of organic evolution are the following:

1. *Diversity of Living Forms.* Variety in the plant world is common knowledge. Obviously every plant had parents. It is equally obvious that oaks do not come from roses. What was the method, therefore, by which we have both oaks and roses? The very fact of diversity indicates change.

2. *The Facts of Geology.* We know from the study of fossil plants that most of the present-day plants did not live in preceding geological ages, and that most of the plants of the former ages are not living now. The evidence suggests that such changes have been gradual.

3. *Comparative Structure.* The study of anatomy shows that certain structures reappear with various modifications throughout whole groups of the plant kingdom. Thus, the archegonium is found in liverworts (low in the scale of life), through the successively higher forms of mosses, ferns, cycads, and gymnosperms, such as the pines. The simplest and most rational explanation is that the different organisms that have archegonia are genetically related; that is, that there is a long line of descent. Also, as one geological period succeeded another through hundreds of thousands of years, the gametophyte phase, originally dominant (as in Mosses and Clubmosses), gradually became subordinate to the sporophyte phase, living parasitically upon it, as in all modern flowering plants.

4. *Life Histories.* On pages 15 to 28 we called attention to the alternation of spore-bearing with seed-bearing generations in the great plant groups. The implication of such similarity of behavior is the same as that of comparative structure.

5. *Geographical Distribution.* Forms that appear to be *genetically* related are found in widely separated continents or regions. Thus the same kind of Lily occurs in different hemispheres. Which is more reasonable: To consider that the same kind originated independently in widely separated countries, or to consider that these lilies had a common ancestry, but became widely disseminated and eventually separated or isolated by the vicissitudes of seed-distribution, and geological change?

How the Vegetation of the Earth Came to Be as It Is

If one had asked, previous to the publication of Darwin's *Origin of Species,* how the plants of the earth came to be distributed as we now find them, the answer would probably have been that they were so "created." Thus Franz Meyen, in his *Outlines of the Geography of Plants* (*Grundriss der Pflanzengeographie*), published in Berlin in 1836, says that studies of the distribution of the different kinds of plants "teach us that nature, *at the creation of plants,* has distributed them over the surface of the earth according to certain laws, which are quite unknown to us." A similar hypothesis was held ten years later (1847) by the Danish botanist, Schouw, who rejected the idea that the present distribution of plants was brought about by dissemination or migration. He considered that the occurrence of the same species in widely separated regions is to be explained by the fact that it was independently "created" in each region. Even Agassiz (1807-1873) taught this, but nothing as to the *method* of creation. Of course, with such a point of view there is an end of the matter. Better wheat, better fruit, better flowers, better method of study would never result from that attitude of mind.

The Limitations of Science

But the ideas of Meyen and Schouw and Agassiz are no longer held, and it is to the painstaking researches of Darwin and Alfred Russel Wallace that we are chiefly indebted for the close approach to the truth which we accept today. For a competent investigator to be mistaken, however, only emphasizes the profound difficulty of trying to explain the phenomena of life. We should ever keep in mind the wise comment of Claude Bernard: "Science does not consist in proving that others are mistaken . . . even if we proved that an eminent man was mistaken, that would not be a great discovery; it can be a profitable work for science only in so far as we show how he was mistaken. . . . We really know very little, and we are all fallible when facing the immense difficulties presented by an investigation of natural phenomena. . . . Indeed, our mind is so limited that we can know neither the beginning nor the end

of things; but we can grasp the middle, *i.e.*, what surrounds us closely."

The greatest result of scientific research is not the solution of problems, valuable as that may be, but the perfection of scientific method and the disclosure of whole groups of new problems that lure us on and challenge our best endeavors.

In the light of the conception of evolution we know that the present distribution of plants came about gradually through the operation of natural laws. If we wish a detailed explanation we must, of course, obtain a comprehensive mental picture of the present and past geographical distribution of plants, and then seek for causes adequate to explain the observed facts. An adequate treatment of the subject would require several volumes, but we may glimpse the problem here in broad outline. We are confronted with the following two groups of facts:

The Panorama of Space

Alexander von Humboldt (1769-1859), founder of the science of plant geography, was one of the first to attempt a detailed description of the present distribution of plants in space. Summarizing the observations made during his wide journeys of exploration, he noted that as one passes from the poles to the equator he finds an increasing profusion of both numbers and kinds of plants. Some species are of very limited range, such for example as the Venus's Fly-trap, a genus with one species (*Dionaea muscipula*), which is found only within a range of a very few square miles (155 miles north and south and about 115 miles back from the sea coast) on the coastal plain of North and South Carolina. Others are of almost universal distribution, such as the Bracken Fern or Brake (*Pteridium aquilinum*), which occurs widely throughout the tropics and the temperate zone in both hemispheres, flourishing in such widely separated regions as Tasmania, North America, East Africa, the Himalaya Mountains, and the Canary Islands. Some whole plant families are nearly or quite confined to one continent, such as the Cactus Family, not found outside of North America (except for one genus, *Rhipsalis*, in South Africa), and the Columellia Family of evergreen shrubs related to the Phlox Family and confined to South America. Others are found in similar climates in different

continents, such as the Palm Family in the warm regions of America, Asia, Africa, and the Pacific Islands. It is an interesting fact that none of the plants under cultivation by the American Indians when America was discovered were then known in Europe.

The Panorama of Time

If we have consciously or unconsciously been laboring under the impression that the plants which now exist have always existed, and that there have never been other kinds of plants which no longer exist, we have only to "dig up" the facts afforded by a study of the plant fossils preserved in rocks. This reveals to us the great botanical panorama of the ages—that, while time passes, new species arise, flourish, and gradually disappear, being replaced by the continuous procession of new forms.

The steps in the process are reproduction, inheritance with variation ("descent with modification" was Darwin's phrase), geographical distribution, natural selection ("struggle for existence" and "survival of the fittest"), the result being the continuous evolution of new forms and the gradual extinction of old forms. This process is still going on.

Fossils tell us that tropical plants formerly flourished in Greenland, the Maidenhair Tree (*Ginkgo*) has become extinct except in cultivation, flowering plants did not exist before the Triassic period, seed-bearing ferns have not existed since the Jurassic, monocotyledons did not appear until the Cretaceous, the Redwoods (*Sequoia*), which in an earlier geological age grew in every continent except Africa, are now found only in the State of California, in North America. Such in brief, is the great botanical panorama of time.

CHAPTER XIX

HOW SCIENCE ADVANCES

The Desire to Know

"The interrogation point is the key to all the sciences," said the great Swiss botanist, Augustin Pyramus de Candolle (1778-1841). The desire to know is the first requisite for science. The possession of this urge to explore and explain the secrets of nature is the chief characteristic of the scientific investigator, whose persistent and repeated endeavors have given rise to the term *research* to designate such work.

Importance of Correct Method

Second only to this is a knowledge of the correct method of procedure. The perfection of scientific method as noted above,

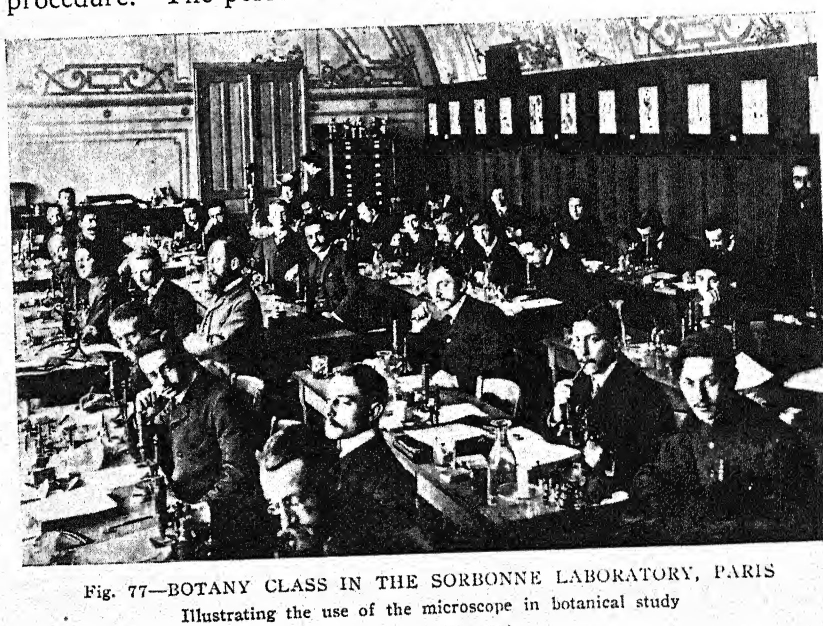

Fig. 77—BOTANY CLASS IN THE SORBONNE LABORATORY, PARIS
Illustrating the use of the microscope in botanical study
(Compare Fig. 78)

is the greatest contribution to knowledge which science has ever made—greater than all the facts and principles which have been discovered by the application of that method, for without a correct method we are only led astray. The first essential of scientific method is that we must study nature directly. In the sixteenth and seventeenth centuries men made the mistake of studying Aristotle (almost exclusively) instead of nature. The procedure is to observe accurately and without prejudice, to compare, classify, generalize, formulate hypotheses as to underlying causes, rigidly test the hypotheses, ruthlessly reject those that do not square with the facts, formulate new ones, and so on, indefinitely, as long as we really wish to know what is true rather than to find support for our prejudices. The late Professor John Henry Comstock of Cornell University used to say to his classes, "Be sure you are right, then look again." As the writer has said elsewhere, "Observe and describe and think; think and observe and describe." To keep an open mind and think straight—this is the only way in which science can advance.

Importance of Scientific Instruments

The limitations of our senses and of our manual skill restrict the possibilities of our knowledge. Thus astronomers could never have known of the mountains on the moon, the rings of Saturn, or sun-spots, except for the *telescope*. The invention of the *microscope* made possible the discovery of cells, bacteria, sperms, chromosomes (the bearers of inheritance in reproductive cells), and all the finer structures of plants and animals.

The *microtome,* which makes it possible to cut sections exceedingly thin (a few thousandths of an inch thick), enables us to view them with transmitted *versus* reflected light. In this way we can observe minute structural features which could not possibly be detected in any other way. Their observation is further facilitated by a method of differential staining, by which various parts take on different colors. By means of the *thermometer* we may accurately measure temperature changes and conditions. The *auxanometer* enables us to measure growth, and the *evaporimeter* to measure the rate and amount of water-loss. Many other instruments of precision might be mentioned

which are in constant use in laboratory and field studies of botany.

Botany and Education

Considering all that has been said in the preceding pages concerning the relation of plants to man and our daily (in fact, hourly) dependence upon plants and plant products, it would seem self-evident that the study of botany should be included in every program for a liberal education. Not, perhaps, that every-

Courtesy of David Griffith

Fig. 78—FIELD STUDY OF BOTANY ON THE AMERICAN DESERT
(Compare Fig. 77)

one should be required to study botany, but it is a fair question whether everyone should not be required to know something of the underlying laws of life (the essentials of biology), and the study of plant life affords one of the best approaches to that subject, including as it does, the subject of photosynthesis and the study of bacteria and molds, which have so important a bearing in human life. Moreover, plants are not unpleasant material to handle in the laboratory, and they lend themselves more readily than do animals to experimental studies. In this preeminently scientific age a first-hand acquaintance with scientific method and biological principles may reasonably be expected as an essential element in a liberal education.

When we come to *practical education,* the preparation for one's chosen lifework, we recognize at once how important a knowledge of plants is for the gardener, the horticulturist, and the farmer, the doctor (all drugs were originally dried plants), the pharmacist, the plant pathologist, forester, plant breeder, landscape architect, and even the legislator who is called upon annually to formulate and pass upon legislation having to do with plant life—witness the Federal and State laws concerning plant quarantines, laws for the control of noxious weeds and those whose pollen causes hay-fever, laws for the conservation of forests and other wild plant life, and various other laws.

Botanic Gardens and Public Education

A botanic garden is a scientific and educational institution for the purpose of advancing and diffusing our knowledge and love of plants. As an aid to their scientific and educational work all such institutions maintain plantations, where hardy plants are grown, and conservatories for tender and tropical sorts. Botanic gardens date from the time of Aristotle, who is said to have endowed with his ample wealth the garden at Athens about 350 years before Christ. Many (perhaps most) of our modern gardens are not separate institutions, but consist only of the plantations developed in connection with the botanical department or institute of a university. The oldest existing gardens of this kind are those at Padua and Pisa, in Italy, both of which were founded about 1545.

It will readily be seen that botanical instruction is greatly enriched by having at hand such a collection of living plants, representing the flora of the entire world, so far as climate permits. Some botanic gardens, such for example as that at Kew (near London), or those at Berlin and Munich, devote most of their resources to botanical research, except as the plantations themselves with their classified collections serve the purpose of public education. A few others have developed definite programs of public education, both independently and in connection with public schools and local colleges and universities.

The most extensive program of public education in plant

life has been developed at the Brooklyn Botanic Garden, where the attendance at classes and lectures has reached the annual total of 100,000 adults and children. In addition to this, the Brooklyn Garden co-operates extensively with the public and private schools of Greater New York in the supply of study material for nature study and botany, conferences with teachers, talks at schools, and in other ways. Over the entrance to the Children's Building is the following couplet from Wordsworth:

He's happiest who hath power
To gather wisdom from a flower.

SUGGESTIONS FOR FURTHER READING

Prepared by the Author

PLANTS AND MAN—*Frederick Orpen Bower* MACMILLAN
A good book for the layman who wishes to understand how plants live and grow. The existing relation between the living plant and the living animal, and many ways in which man's life is bound up in the vegetable kingdom.

OUTLINE OF PLANT GEOGRAPHY—*Douglas Houghton Campbell* MACMILLAN
A brief but interesting treatment of plant distribution which can be read with pleasure and profit by all interested in the vegetation of the earth.

PLANT LIFE AND PLANT USES—*John G. Coulter* AMERICAN BOOK
The fundamentals of plant life emphasizing the relation between plants and man, specially for boys and girls.

EVOLUTION AND SEX IN PLANTS—*John Merle Coulter* CHICAGO
A brief, non-technical survey of the subject for the general reader.

BOTANY OF TODAY—*G. F. Scott Elliot* LIPPINCOTT

ROMANCE OF PLANT LIFE—*G. F. Scott Elliot* LIPPINCOTT
The aim of these books is to present the more recent and human aspects of botany divested of technical terms for the general reader.

WONDER BOOK OF PLANT LIFE—*Jean Henri Fabre* translated by *Bernard Miall* LIPPINCOTT
The great naturalist so well known for his books on insect life, in this book gives his observations on the organization, structure, and growth of plants, and with rare charm describes many wonders of the plant world.

EXPLORING FOR PLANTS—*David Fairchild* MACMILLAN
The human aspects of searching for new economic plants by the head of the plant introduction service of the U. S. Department of Agriculture.

GENERAL BOTANY—*C. Stuart Gager* BLAKISTON
Emphasizes life histories of plants, evolution, and genetics. Chapters on fossil plants.

FUNDAMENTALS IN BOTANY—*C. Stuart Gager* BLAKISTON
Gives special attention to crop plants and other economic plants.

LIVING PLANT—*William F. Ganong* HOLT
A description and interpretation of the structure and function of plants. Addressed "to all who have interest to learn an accurate and vivid conception of the principal things in plant life."

HOW PLANTS GROW—*Asa Gray* AMERICAN BOOK

HOW PLANTS BEHAVE—*Asa Gray* AMERICAN BOOK
Parts I and II of *Botany for Young People* by the greatest American systematic botanist. Still in demand though first printed in the middle of the nineteenth century.

THE STORY OF EVOLUTION—*Benjamin C. Gruenberg* VAN NOSTRAND
Facts and theories in the development of life through the ages. For laymen.

THE SCENT OF FLOWERS AND LEAVES—*F. A. Hampton* DULAU
Facts and theories concerning the scent of plants presented in a non-technical way.

TAXONOMY OF THE FLOWERING PLANTS—*Arthur Monrad Johnson* CENTURY
Intended primarily for the student and instructor of systematic botany, but valuable for reference for the amateur. Richly illustrated.

THE FLOWER AND THE BEE—*John H. Lovell* CONSTABLE
A popular treatment of pollination by bees. Primarily for laymen.

THE GREEN LEAF—*D. T. MacDougal* APPLETON
A popular "Story about Life" as illustrated by green leaves.

CREATION BY EVOLUTION—*Frances Mason* MACMILLAN
Chapters by twenty-six scientific men on the various aspects of organic evolution. Edited by Mrs. Mason.

THE ORIGIN AND NATURE OF LIFE—*Benjamin Moore* HOLT
From electrons and atoms to protoplasm. For the layman.

APPLETON
CARGOES AND HARVESTS—*Donald Culross Peattie*
Popular information about economic plants, such as spices, quinine, rubber, dyes, tobacco, cotton, etc.

REEVES
THE DISPERSAL OF PLANTS THROUGHOUT THE WORLD—*Henry N. Ridley*
Every plant we find in any spot, or one of its ancestors, must have contrived to get there by some means. This book answers the question of "How?" for hundreds of plants in a manner at once scientific and popular.

VAN NOSTRAND
BOTANY—*William J. Robbins* and *Harold W. Rickett*
A textbook for college and university students. Presents fundamental principles of the living world as illustrated by the plant kingdom, and illustrates by concrete examples the aim of science and scientific method.

HOLT
THE EVOLUTION OF PLANTS—*Duckinfield Henry Scott*
A non-technical survey of facts, principles, and theories.

CAMBRIDGE
LINKS WITH THE PAST IN THE PLANT WORLD—*A. C. Seward*
Brief and popular treatment of the many questions concerning the relative antiquity of existing plants as revealed by fossil plants.

CAMBRIDGE
PLANT LIFE THROUGH THE AGES—*A. C. Seward*
Intended for both laymen and scientists. Gives the botanical data which have helped geologists complete the history of the earth.

MELROSE
COMMON PLANTS—*Macgregor Skeve*
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GLOSSARY

[Only those terms are defined in this glossary which either are not explained in the text or are explained once and are used again several pages away from the explanation.]

ALGA (*plural* algae): (from the Latin for "seaweed"), the most primitive of green plants.

ANTHER: the part of the stamen of flowers which develops and contains pollen.

ARCHEGONIUM (*plural* archegonia): the flask-shaped reproductive organ of some plants, in which an egg-cell is formed and an embryo-plant begins to develop.

CALYX: the outer whorl or circle of floral leaves (sepals).

CARBOHYDRATES: neutral compounds including the sugars, starches, and celluloses, composed of carbon, oxygen, and hydrogen, always with twice as much hydrogen as oxygen.

CELL-SAP: the liquid part of protoplasm.

CHLOROPHYLL: the green coloring matter in plants.

CHROMOSOME: one of the small bodies into which the chromatin divides during nuclear division.

CONJUGATION: reproduction by the fusion of two cells (gametes) of similar size.

COTYLEDON: the primary or first leaf of a plant-embryo.

CYCADS: the most primitive living group of seed-bearing plants.

DECIDUOUS TREES: (from the Latin word meaning "to fall"), trees that lose their leaves periodically, usually in the fall.

EMBRYO-PLANT: the product that develops from a fertilized egg-cell. It develops to a certain extent, then commonly undergoes a resting period in the seed until the latter germinates.

ENZYME: (from the Greek word meaning "leavened"), a soluble compound that causes chemical transformation, such as fermentation or digestion.

EPIDERMIS: a thin layer of cells forming the outermost tissues of roots, stems, leaves, and other plant parts.

FUNGUS (*plural* fungi): a thallophytic plant; *i.e.*, one having no true root, stem, or leaf, wholly devoid of chlorophyll, and living as a parasite or saprophyte: such as, mushrooms, puffballs, molds, rusts, etc.

GAMETOPHYTE: a plant that produces gametes (eggs and sperms). In the life-history of a plant, it alternates with the sporophyte phase.

LOAM: soil in which there is considerable decomposed organic matter; often called "top soil."

OVULE: a structure within the ovary of a flower, and containing an egg-cell. After fertilization it develops into a seed.

PHOTOSYNTHESIS: the process by which carbohydrates are formed from inorganic compounds by the chlorophyll of plants in sunlight.

POLLEN: collectively, the tiny grains formed in the anthers of seed-bearing plants. Each grain is a mature microspore (male gametophyte).

PROTEIN: one of the numerous nitrogeneous compounds in plants and animals.

PROTOPLASM: the living substance of all plants and animals, occurring in units called cells.

PROTOPLAST: a unit of protoplasm, comprising cytoplasm and nucleus.

RUST: a parasitic fungus causing disease of cereal grains and other plants.

SAPROPHYTE: a plant living on dead and decaying plants or animals.

SPECIES: a group of plants essentially alike in their fundamental structural characters, and which, through a series of generations, normally produce offspring having the same fundamental characters as themselves.

SPERM: a male reproductive cell, or gamete, fusing with an egg-cell in fertilization.

SPORE: a reproductive body of one or more cells, produced by a sporophyte and developing (without fusion) into a gametophyte.

SPORE-CASE: a structure in which spores are produced.

SPOROPHYTE: a plant that produces spores. In the life-history of a plant, it alternates with the gametophyte phase.

STIGMA: that part of the pistil of a flower which receives the pollen grains and on which they germinate.

STOMATA (*singular* stoma): the tiny holes which perforate the epidermis of the leaves or other parts of plants.

INDEX

WITH PRONUNCIATIONS †

† For key to pronunciation, see page 136.
* Asterisk denotes illustration.

Key to Pronunciation

ā as in dāy	ē as in mēte	ī as in tīme	ŏ as in nŏt
ā̍ " " senā̍te	ē̍ " " ē̍vent	ī̍ " " ī̍dea	ô " " lôrd
ă " " ădd	ĕ " " ĕnd	ĭ " " ĭll	
â " " câre	ẽ " " tẽrm	ĩ " " fĩrm	ū " " ūse
ä " " fär			ū̍ " " ū̍nite
ȧ " " ȧst	ġ = j (gentile)	ō " " ōld	ŭ " " ŭs
	g̃ as in get	ō̍ " " ō̍bey	û " " tûrn